Testing the UARL & ILI approach using a large UK Data Set

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ABSTRACT
The findings and recommendations of the IWA Task Force on Water Losses are summarised in their December 1999 'AQUA' paper. Default values were recommended for parameters used to calculate components of real losses for well-managed water distribution systems in good condition; these had been derived by analysis of a limited sample of international data. The default values are used to calculate system-specific 'Unavoidable Annual Real Losses', and the IWA Level 3 Operational Performance Indicator for Real Losses, the Infrastructure Leakage Index (ILI). The Task Force's approach was validated against four well managed systems, ranges of figures quoted for Unavoidable Real Losses in France, Germany and the USA, and compared with ILI values from 27 water companies across the world.

This paper presents data on minimum achieved background leakage from over 2000 district metered areas {in a major utility in the UK} and compares these data against the task force default values. The paper explores factors relating to the variation of the data between districts and proposes a methodology for the collection, screening and validation of such data sets. Data on total actual losses for the 34 supply zones in the Company are presented in the form of the Infrastructure Leakage Index as proposed by the task force and reasons for variations are explored.

KEYWORDS
Background Leakage, District Metering, Real Losses, Unavoidable Losses, Infrastructure Leakage Index, Leakage Management, Pressure Management, Night Use Allowances

INTRODUCTION

Managing a leakage reduction programme

During 1995 and 1996, water supply operators in the United Kingdom (UK) faced unprecedented drought conditions. In the North West of England, the event has been estimated to have had a return period of once in 300 years. As the drought deepened in 1996, the only way that supplies could be maintained to a population of nearly 7 million was to make significant savings in leakage. The water supply operating company, North West Water (now United Utilities), was forced to embark on a major leakage reduction programme.

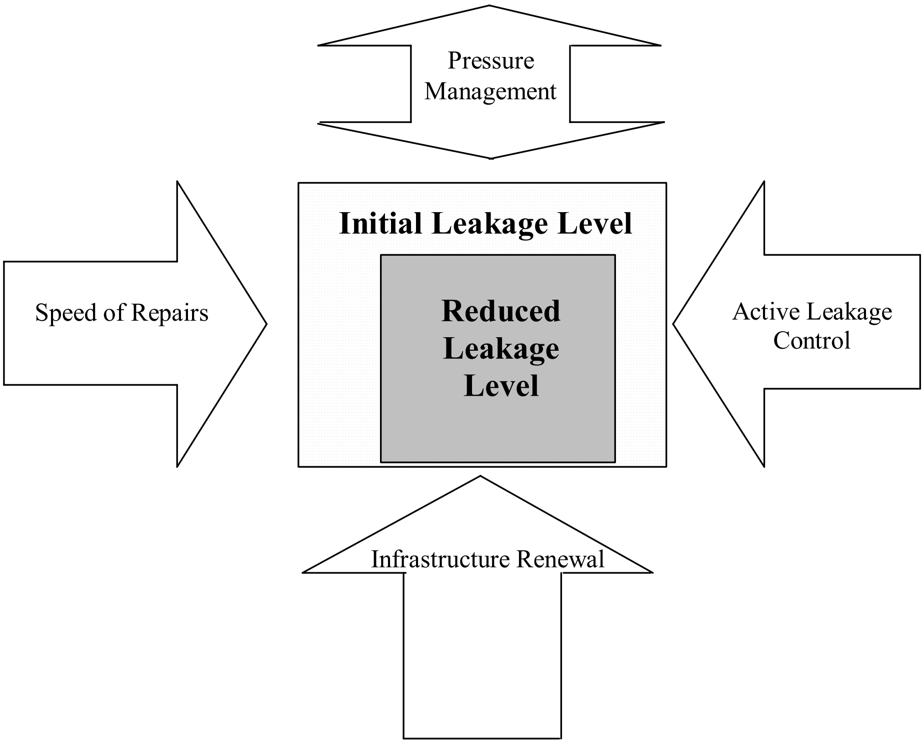
Fortunately, the UK Water Industry had initiated a significant research programme in the early 1990's to update current guidance on leakage management. The results of this work were published in Managing Leakage (WRc, 1994). One of the most important outputs of this research work was the concept of understanding the components of leakage and how these could be estimated. This provided practitioners with the capability of modelling leakage and the factors that affect it. Using these techniques United Utilities (UU) was able to develop a cost effective leakage reduction strategy that allowed supplies to be maintained throughout the drought.

The development of the strategy relied heavily on using the component approach developed as part of UK research work. This concept was referred to as Background and Burst Estimation or BABE. This work has subsequently been developed and extended for international application by the IWA Task Force on Water Losses (Lambert et al, 1999). The component approach relates estimates of background and burst leakage to the following system parameters:

- Length of mains
- Number of service connections
- Length of supply pipe
- Pressure
- Burst rates on the network
- Speed of detection, location and repair
- Infrastructure condition

By understanding the components of leakage, and the relationship between leakage and the infrastructure and management practices that can impact on leakage, it is feasible to model the options available to reduce leakage. This can be represented diagrammatically, see Fig 1.

Figure 1 Diagrammatic Representation of Options for Reducing Leakage



This shows that leakage can be driven down by reducing pressure on the system, improving the speed of detection, location and repair of leaks and also by infrastructure improvements.

One of the major components of leakage, that impacts on how much leakage can be reduced and also impacts on the estimation of the economic level of leakage, is the background level of leakage. This is the level to which leakage can be reduced using current technology. The remaining leakage at this level comprises minor leaks which cannot be detected.

As well as providing a high level modelling tool to aid in the development of a leakage reduction strategy, the component approach can help practical, “on the ground” leakage management by proving an estimate of background leakage at District Meter Area (DMA) level. DMAs are used to monitor leakage levels on small parts on the network usually covering between 500 to 3000 properties. These should be small enough so that a district meter will show when a leak has broken out. However one of the difficulties is knowing if leaks are already running on a DMA when it is initially established. Using the component approach, the expected level of background leakage can be estimated based on the system parameters. The existing leakage level can be compared to this to provide an indication whether there is likely to be existing leaks on the system. It is now common practice in UK leakage management to use this type of analysis to provide a target for each DMA rather than historical minimum levels (Lambert et al, 1996). Any excess leakage can be expressed in the form of the number of “standard” bursts known as Equivalent Service Pipe Burst (ESPBs). These can be used to rank and target DMAs for detection effort. The reliability of the estimate of background leakage is therefore of importance to leakage practitioners.

TESTING THE BACKROUND LEAKAGE PARAMETERS

Component Analysis

In the component approach to estimating leakage, the distribution system is split into the following sections:-

- Distribution mains
- Communication pipes
- Underground Supply Pipes
- Internal Plumbing system

Leakage from each of these sections is then broken down further into

- Background leakage
- Leakage from reported burst
- Leakage from unreported bursts

Table 1 summarises the recommended allowances (Lambert et al, 1999) for losses from a well managed system in good condition.

Table 1 Summary of Unavoidable Annual Real Losses Components

Infrastructure Component	Background Leakage	Reported Leaks	Unreported Leaks	Total	Units
Mains	9.6	5.8	2.6	18.0	l/km mains/day/ metre of pressure
Service Connections, mains to property line	0.60	0.04	0.16	0.80	l/service conn/ day/m. pressure
Underground pipe, where customer meter is located after property line	16.0	1.9	7.1	25.0	l/km of pipe/ day/ metre of pressure

Background leakage represents that leakage which cannot be detected and represents the lowest level to which leakage can be reduced to when all leaks have been detected and repaired. It is feasible to drive leakage down to the background level on a district meter area (DMA) at a given time. However, it is not feasible (and certainly not economic) to drive leakage to the background level simultaneously on a larger zone (say of 50000 properties) made up of many DMAs

In order to test the appropriateness of the background leakage estimates contained in the Task Force recommendations it is necessary to look at the lowest level of leakage achieved in any DMA and compare this to the background leakage estimates from the UARL components.

The components for background leakage used to derive Table 1, in litres/hr at 50m pressure, are shown in Table 2:-

Table 2 Summary of Background Leakage Components expressed as Night Flows

Infrastructure Component	Background Leakage	Units
Mains	20	l/km mains/hr
Service Connections, mains to property line	1.25	l/service conn/hr
Underground pipe, where customer meter is located after property line	33.3	l/km of pipe/hr

In addition to the above a measured night line will include losses from the internal plumbing system. These have been estimated in UK studies to be 0.25l/conn/hr at 50m pressure

The combined estimate of background leakage can be referred to as the Unavoidable Background Real Leakage (UBRL).

Influence of pressure. The UBRL components are normalised for pressure by expressing them as losses that would be expected at 50m pressure. When applying the equation at the UARL level (i.e. including bursts) it is recommended that a linear relationship between leakage and pressure is assumed. However when at or close to the background level, all leakage will at this level be from minor leaks from joints etc. The fixed and variable path philosophy (Lambert, 2001) would recommend that the pressure dependency for background leakage is likely to be to the power of 1.5.

The background leakage on a DMA is therefore estimated by the following equation:-

$$\text{UBRL (m}^3\text{/hr)} = (20 \text{ x } L_m + (1.25 + 0.0333 \text{ x } L_p + 0.25) \text{ x } N_c) \text{ x } (\text{AZNP}/50)^{1.5} \quad \ldots\ldots\ldots\ldots(1)$$

Where:- L_m = Length of mains in km
L_p = Length of typical underground supply pipe in metres
N_c = Number of service connections
AZNP = Average zone night pressure in metres

Approach to Testing the Background Leakage Estimates

In order to test the UBRL estimates it is preferable to have a large dataset – as all aspects of both the estimation and test data will be subject to statistical variance. United Utilities (UU) has over 2200 DMAs ranging in size from 50 to 4000 properties. UU has a varied topology and geography. There are the major conurbations of Manchester and Liverpool and very rural areas of Cheshire and Cumbria. There are reasonably flat plains of Cheshire and the Fylde and the mountainous (UK standard!) areas in the Pennines and Lake District. Connection density varies significantly - 10 to over 300 connections per kilometre and Average Zone Night Pressures (AZNP) can be up to 100m. Because of the significant leakage reduction programme over the last 7 years, which has seen DMA leakage reduced by 60%, many of the DMAs are believed to have been cleared of all leaks at some stage over the last few years. This data set therefore provides the potential for a comprehensive test of the background leakage estimates suggested by the IWA Task Force.

Data was abstracted for all 2200+ DMAs. The historical data was scanned to abstract the lowest achieved night flow. Unfortunately due to a change of computer system in 1999 records were only available for the last 2½ years. A longer period would have been preferable for the exercise. The standard in UU is to abstract night lines as the mean flow between 3.00am and 4.00am as this provides consistency between meters and night allowances. Due to time constraints the absolute minimum hourly flow was abstracted. It is intended that future work would be based on the 7-day average minimum night flow.

Asset data for each DMA was also abstracted. This included:-

- Mains length
- Number of domestic premises
- Number of industrial/commercial premises
- Average Zone Night Pressure (AZNP)

A sensibility scan of this data showed that some of this data was missing from a limited number of DMAs. These DMAs were deleted from the data set. This reduced the data set to 2136 DMAs.

Large industrial users are logged and readings downloaded each week together with the DMA readings. However this is a relatively small proportion of the industrial and commercial meters. The night use for the larger population of non-household customers is estimated using the recommended UK Water Industry methodology (UKWIR, 1999a). The industrial night use is deducted from the minimum night flow.

A domestic night use allowance of 1.7l/prop/hr was applied. This figure was derived as part of the research programme carried out for the development of Managing Leakage (WRc 1994). A more recent UKWIR study (UKWIR, 1999b) has shown this estimate to be possibly conservative.

The UBRL coefficients were applied to the asset data to provide the estimate of the background leakage. A figure of 8m was used as the typical length of an underground supply pipe. In the UK it is general practice to lay a separate connection to each property. It was therefore assumed that the number connections equated to the number of properties.

The ratio of the actual minimum net nightline to the UBRL was then calculated and a cumulative distribution curve produced. This showed a marked plateau at a ratio of 0.3. Inspection showed that 35% of DMAs had a ratio of 0.45 or less. There were a few negative or very low data points. There were also a number of DMAs with high ratios. This was not unexpected. These represent DMAs which have not been cleared of leaks during the last two and half years. The analysis showed that 10% of DMAs had a ratio greater than 5, and 2½% of DMAs had a ratio greater than 10. These latter DMAs are referred to as "blacklist" DMAs – where detailed investigations are continuing to resolve anomalies on the district.

This data was analysed to produce a frequency curve. This curve showed a marked modal value of 0.3 with 19% of DMAs between 0.25 and 0.35. The median value was 1.03. See Fig. 2 and Table 3.

Further investigations were then carried out to look at the impact of a number of data and analytical issues.

Domestic Night Use. As described earlier, a standard domestic night use allowance of 1.7litres/property had been assumed. In practice there is increased statistical error in using this allowance in DMAs with low property counts. This is associated with the likelihood of activity occurring during 3.00am and 4.00am with low property counts. Discussion on this error is included in Report E of Managing Leakage (WRc 1994). This work shows that the error is reduced to acceptable levels with DMAs with more than 500 properties. A filter was therefore applied to eliminate DMAs with domestic property counts less than 500. This produced a marked improvement in the frequency curve in terms of reducing the number of DMAs with ratios less than the mode – see Fig.2. This had the effect of increasing the peak between 0.25 and 0.35 to 21% of DMAs.

Industrial and Commercial Night Use. The use of a standard statistically generated allowance for industrial night use introduces error into the accuracy of the net night line. In order to look at the impact of these assumptions a number of tests were carried out. The data was filtered with different cut-offs of the ratio of night allowance to gross night flow. Cut-offs were applied at 30, 20 and 10%. Application of this cut-off produced a reduction in the standard deviation of the frequency distribution but reduced the peak as well to below 15%. The cut off was therefore lifted to 50% which returned the distribution to sensibly the same as with no cut-off. It was therefore decided not apply any cut-off to further tests.

Flow readings below $Q_{min.}$. There was still a limited number of DMAs with negative or very low ratios. Data for each of these was inspected individually. It was found that, in all cases, the recorded low flow at the time of the lowest night line was in fact below the Q_{min} of the meter. On this basis these data points were removed. The leakage management computer system has the capability of warning users when the meter readings are below Q_{min} and allowing rejection of the data. However not all meters details have been loaded into the system.

Multiple input DMAs. 75% of DMAs are single feed – i.e. they have just one meter recording the flow into the DMA. The remaining 25% of DMAs have more than one input meter or have both input and output meters. Having more than one meter increases the error of the combined flow. The database was scanned to identify which DMAs were single feed and which were multiple feeds. This data was then used to filter the data again to use only single feed DMAs. This increased the peak further to 22%.

DMAs with Bursts. Background leakage requires that all leaks have been identified and repaired. On large DMAs this can require speedy repair. This may be difficult in some situations such as major inner city areas. To investigate this, the data was plotted geographically and inspected to see if there was any predominance of the DMAs with a ratio greater than 5 being in urban areas. This showed that there was a predominance in urban areas indicating the difficulty of speedy and effective leak location and repair in dense urban areas. It was decided to exclude DMAs where the ratio was greater than 5 as this would be indicative of bursts still running on the DMA This reduced the data set by 10% and had the effect of increasing the peak to 23%.

Large DMAs. As part of the leakage reduction programme, UU had split large DMAs into smaller areas. As a result of this work there were only 4 DMAs greater than 3000 properties in the data set. The impact of large DMAs was investigated by removing DMAs with more than 2000 properties. This had no impact on the results and was discarded.

Infrastructure Condition. The UBRL coefficients are for infrastructure in good condition. Areas with older mains and, particularly, services would be expected to have higher leakage. Unfortunately information on the age of mains was limited and there was no data on service pipe age. Further work would be needed when data on refurbishment programmes and pipe age is available.

Pipe Material. Different pipe material could have a marked effect on the background leakage – e.g. a new fully welded polyethylene system would be expected to exhibit very low or no leakage. Further work would be needed to relate the ratio to pipe material.

The results of the analysis of the data are shown in Fig. 2 and the key statistical data are summarised in Table 3.

Figure 2 Frequency Distribution of Background Leakage Ratio

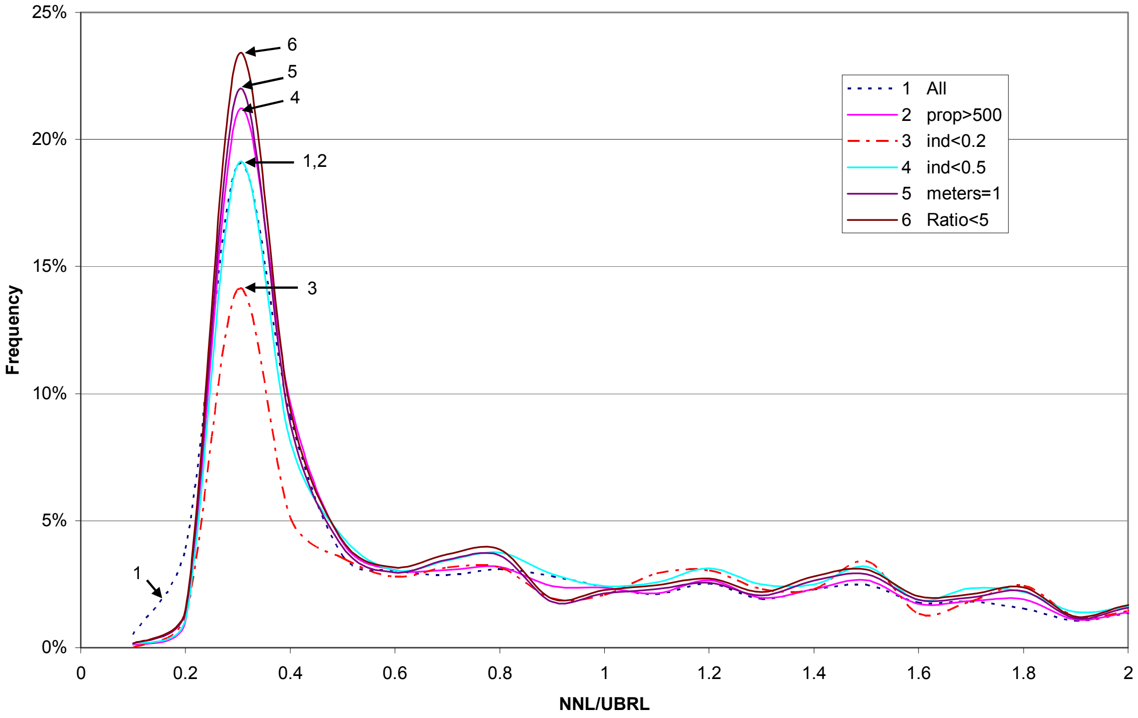


Table 3 Statistical Parameters of Data Sets

	All	prop>500	ind<0.2	ind<0.5	meters=1	Ratio<5
Count	2136	1735	822	1282	1214	1141
% of Original		81%	38%	60%	57%	53%
Mean	2.15	1.87	2.38	1.47	1.70	1.33
Median	1.03	1.03	1.51	1.13	1.03	0.89
Mode	0.3	0.3	0.3	0.3	0.3	0.3
SD	4.11	2.54	3.04	1.21	1.99	1.16

Recommendations

As can be seen in Table 1 the data set available for testing the UBRL estimate is reduced by the application of the rules to reduce the error in the estimate of the real net night line. It is therefore highly likely that in smaller companies there will be insufficient data to carry out this approach. It will therefore be necessary to combine data from different companies in order to generate a large enough sample to provide a valid test of the components of the UBRL.

It is recommend that a standardised approach is adopted to the selection of DMAs to be used in the sample – based on the general approach suggested in this paper together with any necessary modifications gained from discussions and experience of others working in this research field.

The steps needed to improve the reliability of the test are:-

- Agreement on the selection of the minimum night flow (e.g. time of night and duration)
- Agreement on the period of sample of the night flow e.g. 7-day rolling average minimum
- Consider the relationship between number of connections and number of properties
- Exclude DMAs less than 500 domestic connections
- Consider the need to excluding DMAs with high industrial night use component
- Exclude DMAs where the minimum night flows are less than Q_{min}
- Consider rejecting readings below Q2%
- Exclude multiple feed DMAs
- Consider the need to exclude DMAs with large property counts (say >4000?)
- Consider options for removing DMAs where leaks are still present
  - Exclude DMAs with a ratio >5
  - Review connection density as a surrogate of urban area

In order to assist with this type of study it is recommended that leakage management systems include details on meter sizes and valid flow ranges and whether they are single or multiple feed.

It is recommended that further work is carried out to relate the index to pipe age and pipe material.

COMPARISON OF UARL ESTIMATES

The IWA Task Force recommended the derivation of Unavoidable Annual Real Losses (UARL) on areas greater than 5000 properties – see Table 1. In their report (Lambert et al, 1999) they compared real losses against the UARL estimates at company level in 27 companies with a range of system parameters.

United Utilities supply approximately 3m customers. The network is split into 34 demand monitoring zones (DMZs) for management and reporting purposes. These DMZs have property (connection) counts ranging from 3000 to 300000. They cover a range of connection densities from 16 to 126 connections/km and AZNP range from 32m to 57m. The statistics of the DMZs are shown in Appendix 1.

The UARL for each DMZ was calculated using the following formula based on Table 1:-

$$\text{UARL (l/d)} = (18 \times L_m + (0.8 + 0.025 \times L_p) \times N_c) \times (\text{AZNP}/50)^{1.0} \quad \ldots\ldots\ldots\ldots(2)$$

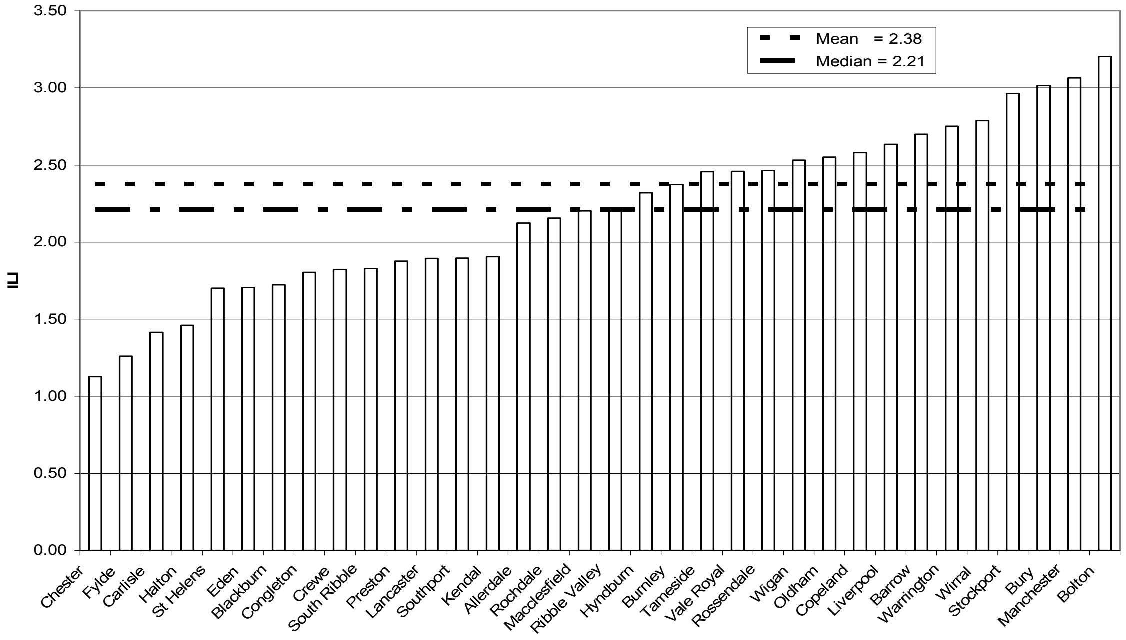
The Task Force recommended the derivation of the Infrastructure Leakage Index (ILI) which expresses the actual leakage in a zone to the UARL. The range of ILI for the 27 companies studied by the Task Force was 0.7 to 10.8 with a median of 2.94 and a mean of 4.38.

Data for the DMZs in United Utilities has been assembled to produce the ILIs for the 34 Demand Zones. This showed a range of 1.13 to 3.2, with a median of 2.21 and a regional average of 2.38. These results are presented in the table in Appendix 1 and shown graphically in Fig 3.

The DMZs associated with the larger conurbations have ILIs greater than the median.

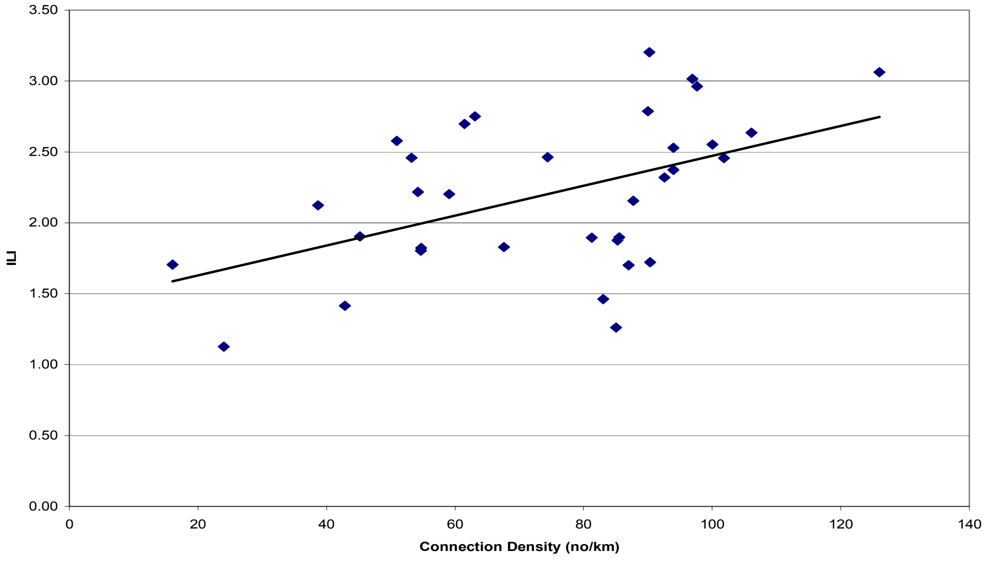
This range of ILI compares favourably with the ranges previously reported in the literature. A figure of 1.0 is expected in an area that is well managed and where the infrastructure is in good condition.

Figure 3 ILIs of 34 Demand Zones in North West England



The variation of ILI was investigated to identify factors that may explain the variation. Fig. 4 shows the variation of ILI with connection density. This shows a marked positive relationship – the higher the density the higher the ILI. This is likely to be a result of the longer location times in more complex urban areas e.g. Manchester and Liverpool. Repair times are also longer in these cities due to road access restrictions. Average asset life, particularly that of service connections, is likely to be higher in these areas as these cities grew dramatically at the time of the industrial revolution in the late 19th century.

Figure 4 Relationship of ILI to Connection Density in North West England



Further inspection showed that there is some relationship of low ILI with the low lying, low pressure areas with a lower percentage of unreported leaks. This tends to support evidence from the Netherlands where low ILI values are attributed to low pressure and sandy soils.

CONCLUSIONS

The publication of the IWA Water Losses Task Force's equation for Unavoidable Real Losses UARL (based on component analysis) has been a significant advance for practical leakage analysis and management.

The allowances for background losses (UBRL) proposed by the Task Force have been tested against a large data set form one UK water supply company. This analysis indicated that the allowances may overstate the possible minimum level of leakage that could be attained on an individual District Meter Area. However a number of issues were identified in respect of interpreting the data and it is proposed that further studies should be carried out.

The data for the same large water supply company was analysed at Demand Zone level to derive the Infrastructure Leakage Index. The allowances recommended by the IWA Task Force were used for total Unavoidable Real Losses (UARL). The ratios of actual losses to unavoidable losses (ILI) were derived and ranged from 1.13 to 3.2. These are in line with ratios found on other studies of well managed systems and therefore provide further confidence in the use of the UARL approach on large supply zones.

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Appendix 1 Demand Zone Data for United Utilities

DMZ	No of DMAs	Mains km	Domestic Props no	Total Props no	AZNP m	Connection Density no/km	NFCUAN Ml/d	Actual MNF Ml/d	Actual NNF Ml/d	UARL Mains Ml/d	Service Connection Ml/d	UGSP Ml/d	UARL Ml/d	ILI
Allerdale	49	966	33969	37390	52	39	7.2	13.8	5.1	0.8	1.3	0.3	2.4	2.12
Barrow	40	847	46835	52074	35	61	4.8	13.9	6.9	0.7	1.5	0.4	2.6	2.70
Blackburn	49	570	46080	51477	40	90	3.6	10.8	5.1	0.5	2.0	0.5	2.9	1.72
Bolton	95	1432	117375	129145	41	90	6.0	30.3	18.8	1.0	3.9	1.0	5.9	3.20
Burnley	57	763	64652	71690	36	94	8.5	21.7	10.1	0.7	2.9	0.7	4.3	2.37
Bury	49	647	56807	62739	57	97	4.0	16.4	9.8	0.5	2.2	0.5	3.2	3.02
Carlisle	55	1131	43924	48464	47	43	3.5	9.6	4.1	0.9	1.6	0.4	2.9	1.41
Chester	8	259	5652	6227	43	24	0.5	1.5	0.7	0.3	0.3	0.1	0.6	1.13
Congleton	28	741	36603	40487	38	55	4.2	10.0	4.1	0.6	1.4	0.3	2.3	1.80
Copeland	32	598	27697	30474	42	51	1.8	8.5	5.4	0.6	1.2	0.3	2.1	2.58
Crewe	35	889	43910	48688	36	55	4.2	10.9	4.7	0.7	1.5	0.4	2.6	1.82
Eden	38	1310	18816	21041	37	16	2.2	7.7	4.6	1.5	1.0	0.2	2.7	1.70
Fylde	107	1716	131543	145981	37	85	14.0	28.1	7.9	1.1	4.1	1.0	6.3	1.26
Halton	35	583	43447	48456	48	83	15.2	20.8	3.6	0.4	1.6	0.4	2.4	1.46
Hyndburn	34	408	33501	37732	43	93	1.9	8.1	4.6	0.3	1.3	0.3	2.0	2.32
Kendal	32	764	31106	34538	45	45	4.6	10.6	4.5	0.7	1.3	0.3	2.4	1.90
Lancaster	62	678	48603	55051	39	81	5.2	12.3	4.8	0.5	1.6	0.4	2.6	1.89
Liverpool	204	3026	290128	321117	35	106	18.5	66.5	34.5	1.9	8.9	2.2	13.1	2.63
Macclesfield	47	1083	57787	64025	44	59	4.3	14.2	7.1	0.7	2.0	0.5	3.2	2.20
Manchester	246	3056	346816	385171	50	126	31.2	91.0	43.6	1.8	9.9	2.5	14.2	3.06
Oldham	70	913	81683	91295	38	100	3.7	18.6	11.1	0.7	2.9	0.7	4.3	2.55
Preston	50	768	58713	65485	45	85	3.9	12.1	5.4	0.5	1.9	0.5	2.9	1.87
Ribble Valley	20	301	14653	16311	48	54	1.1	4.5	2.7	0.3	0.7	0.2	1.2	2.22
Rochdale	64	1010	80256	88580	38	88	4.5	18.7	10.5	0.8	3.2	0.8	4.9	2.16
Rossendale	22	400	26811	29753	40	74	1.6	7.2	4.4	0.4	1.1	0.3	1.8	2.46
South Ribble	55	990	60393	66934	49	68	5.0	14.4	6.6	0.8	2.3	0.6	3.6	1.83
Southport	74	1202	92764	102841	35	86	7.1	20.3	8.9	0.9	3.1	0.8	4.7	1.90
St Helens	32	533	41791	46325	37	87	2.6	8.0	3.5	0.4	1.3	0.3	2.0	1.70
Stockport	102	1333	117264	130166	39	98	3.8	25.8	16.5	0.9	3.8	0.9	5.6	2.96
Tameside	81	1160	105871	118129	42	102	4.9	22.8	12.9	0.8	3.6	0.9	5.3	2.46
Vale Royal	36	895	43209	47649	36	53	3.4	12.6	7.2	0.8	1.7	0.4	2.9	2.46
Warrington	50	1305	73511	82285	43	63	9.3	24.0	11.3	0.9	2.5	0.6	4.1	2.75
Wigan	90	1340	113198	125927	32	94	6.8	26.7	14.6	0.9	3.9	1.0	5.8	2.53
Wirral	88	1534	124839	138057	38	90	10.1	35.1	19.2	1.1	4.6	1.1	6.9	2.79
Total	2136	35150	2560207	2841704	39	81	213	658	325	26	88	22	137	2.4