# Comparing Leakage Performance using the Frontier Approach

**D Pearson, S W Trow**

David Pearson Consulting, Cliff Road, Acton Bridge, Northwich, Cheshire, CW8 3QY, UK

david.dpc@btinternet.com

Trow Consulting, The Vineries, Crichton Avenue, Chester-le-Street, Co Durham, DH3 3ND, UK

stuarttrow@hotmail.co.uk

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## Background

The choice of the most appropriate indicator to use to compare leakage performance between companies or zones has been the focus of much research and study. The IWA Water Loss Task Force made recommendations (Lambert, 2000) about standardising the terminology and the water balance and then went on to show the short comings of some performance measures. It introduced the concept of the unavoidable level of losses and the Infrastructure Leakage Index. The Water Loss Task Force reviewed the recommendations on key performance indicators in 2007 (Liemberger R, 2007), A recent project in the UK (Watershed, 2011) to update the original Managing Leakage (WRc, 1994) has also reviewed this previous work. This review highlighted a number of new approaches and in particular the Frontier approach.

The work reported here has looked at a number of key indicators and applied them to leakage performance within 33 zones ranging from 7000 to 400,000 properties within a large operating company in the UK. The intention of the study was to compare the results from using the different indicators and to investigate whether the Frontier approach had any advantages over other indicators. In addition the use of the Frontier method to benchmark performance and set internal targets at zone level has been investigated.

## Data Requirement

In practice it has been found that the majority of the variance in leakage performance can be explained by a small number of explanatory factors and that there is little to be gained by adding more and more complex factors. The number of variables must be less than the number of zones. A limited number of key, readily available factors have been used as part of this study. Further factors could be investigated if this was considered worthwhile.

The following data abstracted from the company leakage management system:

- Length of mains
- Property count
- Average Zone Night Pressure (AZNP)
- Hour to day factor (HDF)
- Annual average leakage
- Average supply pipe length
- Average annual number of leak repairs (four year average) split by source (reported or unreported) and type (mains, to edge of street, from edge of street-supply pipe)

## Key Performance Indicators

### *Percentages*

Although the use of percentage loss (leakage/distribution input) is commonly used by the public and non-technical press it is now accepted within the industry that the use of percentages is not appropriate when comparing performance. The primary reason is because DI includes consumption which can vary considerably even within a country let alone around the world. Two companies with similar leakage levels but with different consumption rates would therefore have different losses when expressed in the form of percentage of distribution input. The other disadvantage of using percentages is that it discourages efficient use of water as reductions in water use would make it look as though leakage performance had deteriorated.

### *Loss per connection and losses per km*

The "simplest" indicator of leakage performance is to express leakage in the form of either loss per service connection or loss per km of main. In practice most companies do not have precise details of their service connections so the number of billed premises is usually used as this is readily available from financial systems. Figure 1 shows the leakage in the 33 zones expressed in litres per property per day plotted against connection density in m/prop. Figure 2 shows the alternative of expressing in m3 per km of main.

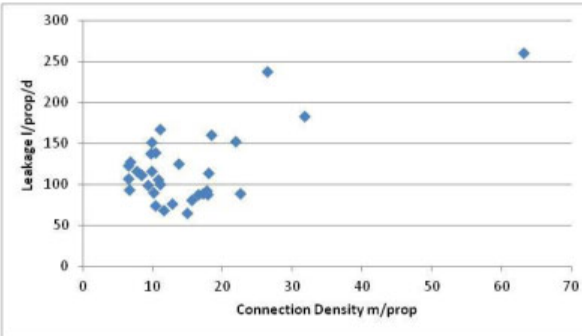


**Figure 1** Losses per property against connection density

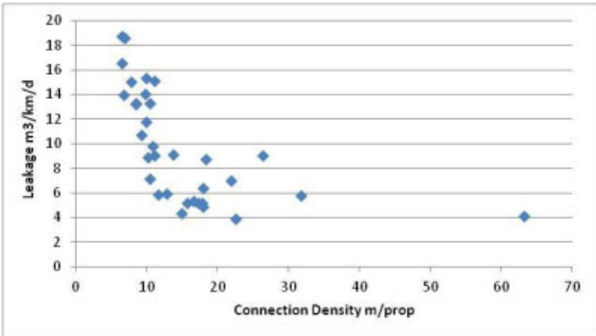


**Figure 2** Losses per km against connection density

The graphs show that both measures have a high correlation with connection density. So l/prop/d disadvantages rural zones and m3/km disadvantages urban zones. This shows that the measures are not satisfactory indicators to compare performance.

One solution suggested to avoid this is to use l/prop/d for urban zones but use m3/km/d for rural zones. This has two problems. Firstly, a cut off has to be agreed (for example 20m/prop or 50prop/km would be suggested from Figure 2) but the actual level used could be viewed as arbitrary. Secondly, and more importantly, it has the effect of splitting the population of zones into two groups and it is not possible to compare performance between the two groups.

### *Loss per km of total system length*

A solution to this issue, suggested in Managing Leakage (WRc, 1994), is to express performance as a ratio of total system length. This is the sum of the length of mains and the total length of service pipe. This is shown in Figure 3

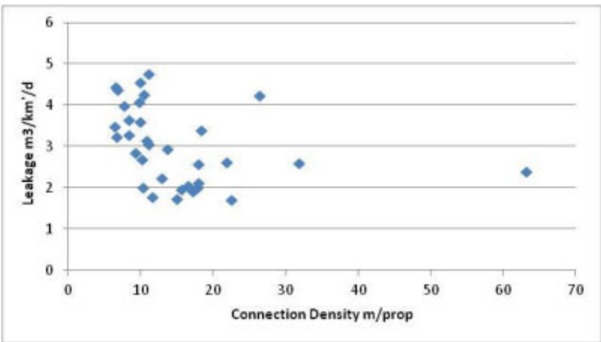


**Figure 3** Loss per total system length against connection density

The use of total system length has had the effect of “levelling” out performance between urban and rural zones and as such is a more satisfactory measure.

***Scatter plot***

An alternative way of coping with the problem of urban/rural systems is to plot the information in the form of a scatter plot with losses in m3/km/d plotted against l/prop/d. This form of presentation was used by Ofwat to compare performance between companies in England and Wales until recently. This approach is shown in Figure 4.

The difficulty with this approach is to know how systems should be compared. If leakage is reduced then the zonal performance will track along the line towards the origin the slope of which is the connection density of the zone. The urban DMAs have a steeper line to the origin whereas the rural systems have flatter lines to the origin. Therefore the nearer a zone is to the origin compared to another zone with similar connection density then the better the performance. It is feasible to compare systems which are on similar lines towards the origin. This is shown in Figure 4.

The four zones that lie along the red line can be ranked against each other and similarly the 12 zones that lie approximately on the green line and can be ranked against each other. However, it is difficult to compare performance between the groups and it may be difficult to decide how many lines (and hence groups) to use to represent the whole population. The process therefore becomes unworkable particularly with low numbers of zones

It is often considered that zones should “gravitate” to a rectangle towards the origin but this is not correct. Lines of equal leakage would in fact be inverse curves between the two axes. This is shown in Figure 5.

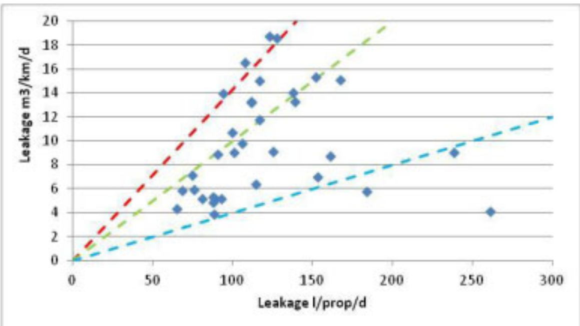


**Figure 4** Scatter plot showing lines of equal connection density

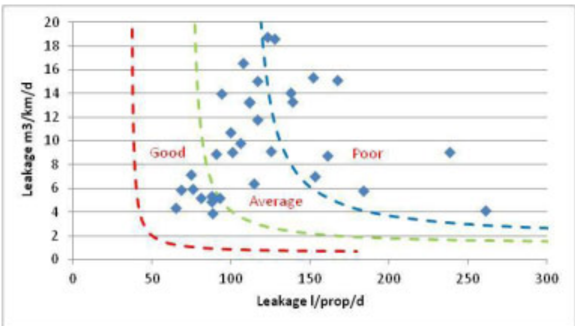


**Figure 5** Scatter plot showing curves of equal leakage

Using this approach it is possible to take a view on the relative performance between companies although it can be difficult to obtain quantitative values. It is therefore easier to use this approach to generate operational bands such as “good”, “average”, “poor” using isoclines as shown in Figure 5.

The problem with this approach is that assumptions have to be made on the relative loss on mains compared to connections and this could be considered a drawback. The curves shown on Figure 5 have been drawn based on the assumptions in the calculation of the ILI (discussed in the next section).

***Infrastructure Leakage Index***

The International Water Association (IWA) Water Loss Specialist Group (WLSG), previously known as the Water Loss Task Force (WLTF), developed a key performance indicator with the intention of addressing the issue of developing a quantitative method of comparing performance between systems (Lambert A, 2000). The approach is based on the concept of estimating the unavoidable level of losses for a system of the same size as the system being considered. This is referred to as the Unavoidable Annual Real Losses (UARL). The UARL is a function of the length of mains, the number of connections, the length of the supply pipe and the average operating pressure. The value of losses used to assess the UARL is based on a wide survey of systems across the world. The “best” achieved have been chosen for the level of background leakage, the assumed burst frequencies and the assumed run time of leaks. Standard flow rates are assumed and adjusted for the average operating pressure of the system. Details of the assumption are given in the reference (Lambert A, 2000).

The Infrastructure Leakage Index (ILI) is then evaluated by expressing the current level of leakage as a ratio of the UARL. A simple ratio is therefore produced. It is highly unlikely to have a value of less than 1 other than in exceptional circumstances. A value of 2 means that the level of leakage is twice that which could be expected on a system of the same size and operating at the same pressure if it was in good condition and well managed.

The ILIs for each zone have been evaluated and the results shown in Figure 6. This shows a range from 1.2 (best) to 2.7 (worst).

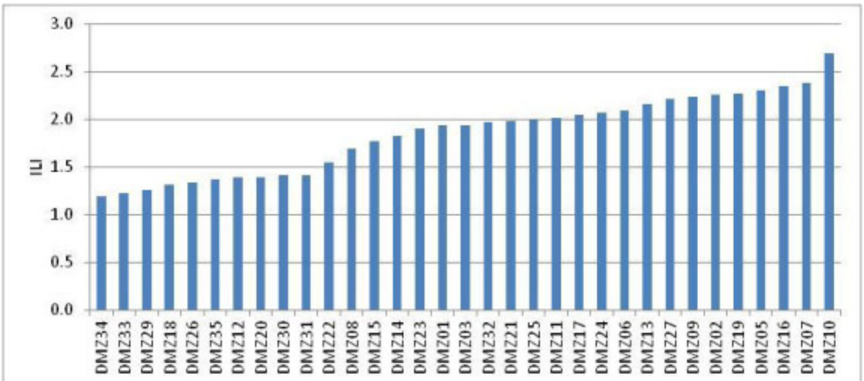


**Figure 6** ILIs for the 33 zones in the study

In many respects the ILI is a measure of the potential for improvement in leakage from active leakage control. High ILIs may be due to mains in poor condition with high burst frequencies. If actual burst frequencies are not significantly higher than those assumed in the calculation of unavoidable losses then it is worth investigating the minimum historic night flows (Pearson, 2009).

### *The influence of pressure - the Pressure Management Index*

It is known that pressure has a significant impact on leakage. Trow has proposed (Trow, 2009) the use of a Pressure Management Index (PMI) as an indicator of the potential for pressure management. The PMI is defined as the actual pressure above a reference pressure expressed as a ratio of the reference pressure. Hence, a value less than 1 would indicate that service standards were not being met. A value of 1.5 probably represents a sensible minimum. A value of 2 would indicate that average pressure was twice that of the reference standard. Figure 7 shows the PMIs for the 33 zones using the UK reporting level of 15m as the reference pressure.

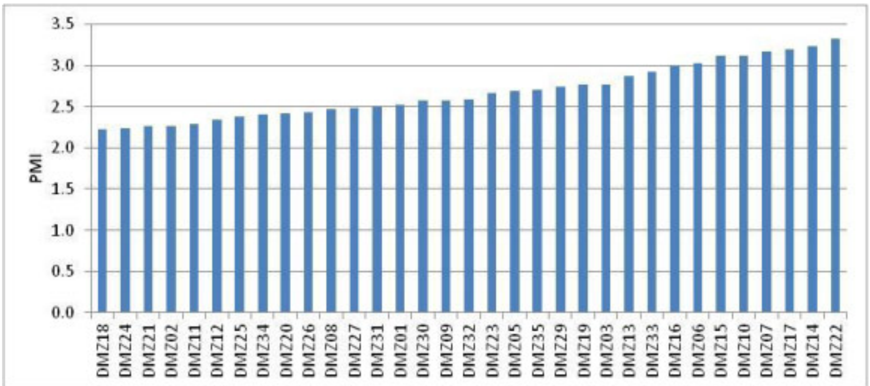

**Figure 7** PMIs for the 33 zones in the study

It is suggested that the PMI could be a useful indicator of the potential for further pressure management. Areas which are relatively flat but have high PMIs could have significant potential for pressure management, provided that limiting factors such as supplies to high rise buildings can be overcome

### *Combining ILI and PMI*

Trow (Trow, 2009) suggested that combining the ILI and PMI may be a good indicator for identifying leakage management priorities. This is shown for the zones in the study in Figure 8.

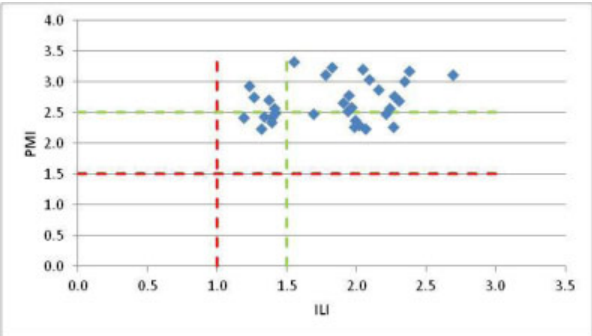

**Figure 8** Plot of PMI and ILI for the 33 zones

The red lines indicate the infeasible limits. The green lines indicate a possible boundary between performance levels (World Bank A1 and A2 in the case of ILI). An indication of where effort should be applied is given by looking at where a zone is in relation to these lines. Thus:

- ILI<1.5 and PMI <2.5: acceptable performance - 6 zones
- ILI >1.5 but PMI<2.5: investigate ALC - 7 zones
- ILI<1.5 but PMI >2.5: investigate pressure management - 4 zones
- ILI>1.5 and PMI>2.5: investigate ALC and pressure management - 16 zones

## The Frontier Approach

The Frontier approach was investigated by WRc (WRc, 2008) as part of the follow up to the Quinquepartite Review (WRc, 2007). In essence the approach is to look at a model that best explains the performance on leakage using a number of normalisation and explanatory factors. By looking at actual leakage compared to the predicted leakage a ratio is produced that can be used to rank the performance of the individual areas. The process is very similar to that used in the econometric studies of company performance carried out by Ofwat (Ofwat, 2009) where unit costs of operation are compared. In the case of the study by WRc, a large number of normalisation and explanatory factors were considered but a much reduced list of factors have been considered in the work reported here.

As with the WRc study it was decided that it is best to use a model that has some basis to the physical relationship expected rather than a purely “black box” approach. The advantage of having some basis to what might be expected is that the model will generally be more acceptable to practitioners in the field.

Two models were investigated. The first postulates that leakage occurs on mains, on the connection from the main to the edge of street and on underground supply pipes and is therefore dependent on the extent of these assets. It further postulates that leakage on these assets is independent and therefore additive. It also postulates that leakage is related linearly to average operating pressure on the system. This model is therefore identical to the model for UARL. This is referred to as Model 1.

The second model is similar to Model 1 but with the addition of leakage related to the number of bursts on mains, connection pipes and underground supply pipes. These bursts are split between those that are reported by customers and those that are detected through active leakage control. Again these elements of leakage are assumed to be independent and also to be related to pressure. This is referred to as Model 2.

### *Model 1 – Leakage as a function of DMA attributes*

The model postulated was:

$$\mathbf{L = (a_1 \times L_m + a_2 \times N_{props} + a_3 \times L_{UGSP}) \times AOP} \qquad \text{..........Equation 1}$$

Where:

- $L$ = Annual average Leakage (Ml/d)
- $L_m$ = Length of mains (km)
- $N_{props}$ = Number of properties (this should preferably be connections but since there is no data on connections, properties have been used instead)
- $L_{UGSP}$ = Estimate of length of supply pipe based on average supply pipe length and number of properties (km)
- AOP = Average Operating Pressure (= AZNP x 24/HDF) (m) where AZNP is the Average Zone Night Pressure, and HDF is the hour to day factor

The parameters $a_1$, $a_2$ and $a_3$ were found which minimised the sum of the squares of the differences between the modelled and actual leakage. It was decided to use the sum of the squares of the difference of the log of the leakage so that large zones did not overly outweigh the small demand zones. The optimum values of the parameters were as follows:

- $a_1$ = 780 l/km/d at 50m = 16 l/km/d per metre of pressure
- $a_2$ = 90 l/prop/d at 50m = 1.8 l/prop/d per metre of pressure
- $a_3$ = 1.9 l/m/d at 50m = 38 l/km of supply pipe/d per metre of pressure

The sum of the squares of the error was 1.58. The average ratio between modelled and actual was 1.02 and the standard deviation was 0.22. The lowest ratio was 0.66 and the highest ratio was 1.61.Figure 9 shows a plot of modelled leakage against actual leakage for each zone. Figure 10 shows the same data but plotted in a log-log form which reduces the clustering near the origin due to the range of size of zones.

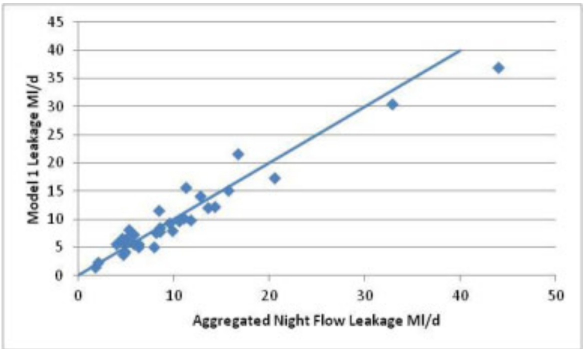


**Figure 9** Plot of modelled leakage against actual leakage for Model 1

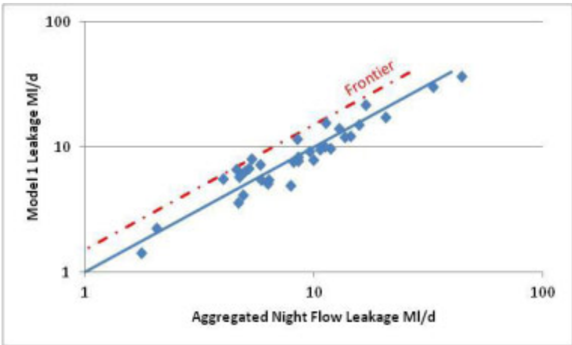


**Figure 10** Log-log plot of actual and modelled leakage using Model 1

The Frontier performance is defined by the zone with the lowest ratio of actual leakage compared to modelled leakage. This can then be shown as a line (or Frontier) to which other zones should aspire. This is shown in red on Figure 10. The scores of the other zones are then calculated as a ratio to this score. Thus the scores range from 1 upwards, with the zone with the highest ratio of actual to modelled leakage having the highest score.

As stated earlier this form of model is equivalent to the model for the UARL discussed in the section on ILI. . In the case of the unavoidable losses the coefficients are:-

- $a_1$ = 18 l/km/d per metre of pressure
- $a_2$ = 0.8 l/prop/d per metre of pressure
- $a_3$ = 25 l/km of supply pipe/d per metre of pressure

The value of the parameters between Model 1 and UARL are of the same order with the mains being very close but the losses on connections and supply pipes being higher.

### *Model 2 – Leakage as a function of DMA attributes and bursts*

The model postulated was:

$$L = (a_1 x L_m + a_2 x N_{props} + a_3 x L_{UGSP} + a_4 x N_{repm} + a_5 x N_{repc} + a_6 x N_{reps} + a_7 x N_{unm} + a_8 x N_{unc} + a_9 x N_{uns}) \text{ x } (AOP/50)\text{^}n1$$

**..........Equation 2**

Where:

- L = Annual average Leakage (Ml/d)
- $L_m$ = Length of mains (km)
- $N_{props}$ = Number of properties
- $L_{UGSP}$ = Estimate of length of supply pipe (km)
- $N_{repm}$ = reported mains burst frequency (no/yr)
- $N_{repc}$ = reported communication pipe burst frequency (no/yr)
- $N_{reps}$ = reported supply pipe burst frequency (no/yr)
- $N_{unm}$ = unreported mains burst frequency (no/yr)
- $N_{unc}$ = unreported communication pipe burst frequency (no/yr)
- $N_{uns}$ = unreported supply pipe burst frequency (no/yr)
- AOP = Average Operating Pressure (= AZNP x (T or HDF)/24 (m) where AZNP is the Average Zone Night Pressure, T is the hours the system is pressurised or HDF is the hour to day factor)

The parameters $a_1$ to $a_9$ and n1 were found which minimised the sum of the squares of the differences between the modelled and actual leakage. Again the sum of the squares of the difference of the log of the leakage was used so that the very large zones did not overly outweigh the small zones. The optimum values of the parameters were as follows:

- $a_1$ = 0 l/km/d at 50m = 0 litres/km/d per metre of pressure
- $a_2$ = 77 l/prop/d at 50m = 1.5 litres/property/d per metre of pressure
- $a_3$ = 1.0 l/m/d at 50m = 20 litres/km of supply pipe/d per metre of pressure
- $a_4$ = 0 m3/burst at 50 metre of pressure
- $a_5$ = 1.7 m3/burst at 50 metre of pressure
- $a_6$ = 0 m3/burst at 50 metre of pressure
- $a_7$ = 9.9 m3/burst at 50 metre of pressure
- $a_8$ = 7.4 m3/burst at 50 metre of pressure
- $a_9$ = 8.7 m3/burst at 50 metre of pressure
- n1 = 1.08

The sum of the squares was 1.06 showing a significant improvement over Model 1. The values of the parameters, $a_2$ and $a_3$ are similar to those using Model 1 but smaller now that they do not include burst leakage. The value of 0 for $a_1$ is not to be expected but has probably been affected by the level of leakage on unreported mains bursts. The value of 0 for reported mains burst is probably an accurate reflection since it is unlikely the method of leakage assessment used in this case was unlikely to include reported mains burst leakage. The value of 0 for reported supply pipe burst leakage is not expected unless it reflects very short run times as the operator offers a free repair service for customers. The values for the volume lost from the reported communication pipe burst and all the unreported bursts are probably a good reflection of the actual losses. These values translate into sensible flow rates when assumptions are made of run times that might be expected on average.

Figure 11 shows a plot of modelled leakage against actual leakage for each zone in a similar fashion to Figure 10. The ratios of actual to modelled leakage were calculated. These ranged from 0.66 to 1.62. Figure 12 shows a frequency distribution curve of these ratios. This shows a distribution close to a normal distribution for the main body of the data. It shows how much one zone is an outlier to the rest of the population. This distribution can be used to band operational performance; for example, using upper quartile, central 50% and lower quartile.

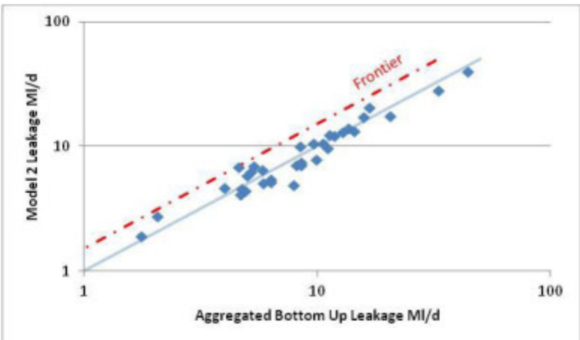


**Figure 11** Plot of modelled and actual leakage using Model 2

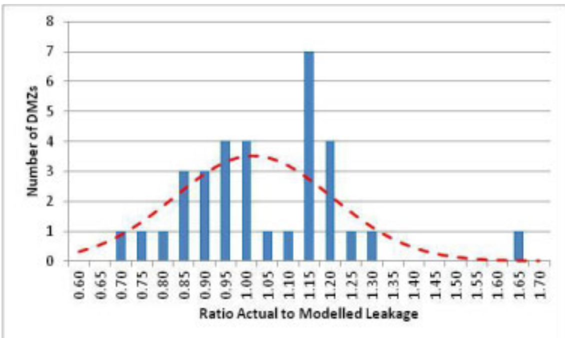


**Figure 12** Frequency distribution curve of ratios of actual to modelled leakage

A number of tests were carried out to investigate any bias in the results. This was carried out by plotting the ratio against various variables such as connection density. Connection density is a surrogate for the property density and could therefore reflect the difficulty of access to carry out leakage detection and repair. These tests showed that the ratio was independent of these variables and therefore it can be assumed that the model is reasonably robust.

A pattern was observed that the best performing districts were geographically close to each other and lie in areas with predominantly sandy soils. There is evidence (WRc, 2006) that leakage can be lower in sandy areas due to leaks rising to the surface easier. It would therefore be worth studying this further and if appropriate identifying a factor related to ground type and including this in the model.

### *Comparison to ILI*

Figure 13 shows a plot of the Frontier score for Model 1 compared to the ILI. This shows a close relationship which is due to the fact that the two models for leakage are of the same form. Figure 14 shows a plot of Frontier scores compared to ILI for Model 2. This time there is a wider spread showing how burst frequency has affected the Frontier scores whereas the ILI does not reflect actual burst frequencies.

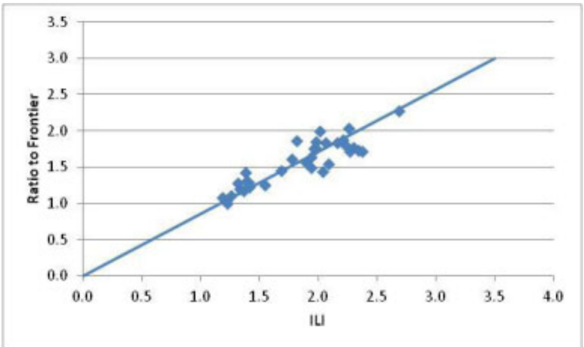


**Figure 13** Comparison of Frontier score to ILI for Model 1

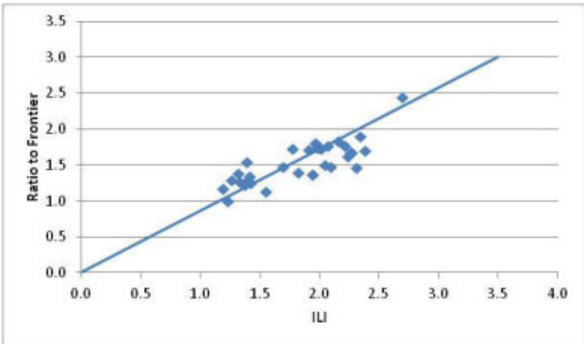


**Figure 14** Comparison of Frontier score to ILI for Model 2

## Using the Frontier scores to set targets

The Frontier scores can be used to set targets based on the presumption that if the model is robust then the modelled leakage is a good estimate of the leakage that could be achieved. In fact it can be argued that other zones should strive to achieve the performance of the Frontier zone. However it may be argued that it is unrealistic to set targets based on the Frontier zone itself until the reasons for the high performance are investigated and understood to make sure that the data is robust and realistic. Figure 12 shows that in this study the best performing zone is not an outlier so the data is probably realistic but to set targets based on this is still probably unrealistic in the short term. If all zones managed to achieve the performance of the Frontier zone then leakage would be a third lower for the operator as a whole.

It would however be more realistic to set targets based on the performance achieved in a reasonable percentage of zones. A more realistic target would be to aim for the performance achieved or bettered in 25% of the zones. Zones which have a leakage performance which is better than this score would be expected to maintain their performance whilst zones in which the performance is worse than this score would be set targets equivalent to achieving this score. Setting targets in this way should drive leakage reductions of the order of 15% for the operation as a whole. This may take several years and intermediate targets could be set at, say, the 75% and 50% scores in the interim.

## Conclusions

A number of conclusions have been drawn from the study:

- Although a number of different performance measures have been proposed to compare leakage between areas, there are significant drawbacks to most for one reason or another. This study has shown that the use of the Frontier approach can overcome many of these drawbacks. The approach can be used to set targets to drive out reductions and improvements in leakage performance.
- Although the Frontier approach cannot indicate what measures should be taken to improve performance, the use of the PMI and ILI indices can provide an indication of the relative priority of leakage detection or pressure management. The first priority must however be to check the quality of the data to ensure that the data reflects actual performance accurately.
- The use of the Frontier approach can identify the best and worst performing zones. Detailed benchmarking between these zones should be able to identify the reasons behind this to support operational changes and improvements.
- If targets are set using the Frontier zone itself then it is essential that data on this zone is checked thoroughly. If however, targets are set on average or other percentage performance then this is not as critical.
- No account has been taken of the security of supply or the cost of water in the present study.
- The Frontier approach can help indicate additional factors (such as the ground conditions in this case) for further investigation.
- The Frontier approach can be used to compare performance between different organisations but it may be necessary to take into account the differences in the cost of water and the supply demand balance.

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