# Pressure management extends infrastructure life and reduces unnecessary energy costs

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## Abstract

Pressure management encompasses several approaches and has a number of important benefits; it has been referred to as *"the preventative method par excellence"* of water loss management. Whilst changes in leak flow rates and some components of consumption are now reasonably predictable (Thornton and Lambert, 2005), there has been little published data as to how improved management of excess pressures and surges can influence new break frequency of mains and services.

This paper summarises pressure: break frequency data, provided by members of the Pressure Management Team of the IWA Water Loss Task Force (WLTF), from over 100 international examples. Reductions in new break frequency are shown to be significant, typically ranging from around 25% to 90%, and averaging around 50%. The latest WLTF conceptual approach to understanding and predicting why and how such large reductions are achievable is also outlined. Several case studies are presented from Utilities where the results of pressure management implementation have been tracked and compared with the latest method of prediction. Implications for infrastructure management and energy management will be considered more fully in other future papers.

## Progress since Leakage 2005

### *Review of Leakage 2005 papers on this topic*

At the Leakage 2005 Conference two papers (Thornton & Lambert, 2005; Pearson et al, 2005) presented data on new break frequencies, on mains and/or services, *'before'* and *'after'* the introduction of pressure management. The results presented generated considerable interest, as they generally showed significant and immediate reductions in break frequency following pressure management.

In both papers, the authors – all Water Loss Task Force members - had previously agreed that the data would be analysed and presented using the provisional hypothesis that break frequency BF varies with pressure P to the power N2, i.e.

$$\text{BF varies with } P^{N2}, \text{ or } \quad BF_1/BF_0 = (P_1/P_0)^{N2}$$

as this form of equation had previously been successful in representing FAVAD relationships between pressure and leak flow rates (using an exponent N1), and pressure and consumption (using an exponent N3).

The results showed N2 exponents varying between 0.2 and 12. However, it was evident from the analyses (notably Fig 9 of Pearson et al) that the high N2 values were strongly associated with small % reductions in pressure, and low N2 values with larger reductions in pressure. This showed that the 'N2' approach for analysis and prediction of pressure: break relationships was clearly inappropriate.

*Progress since Leakage 2005*

Principal authors of the two papers exchanged views during early 2006, and agreed:

- that the N2 approach to analysis should be abandoned as inappropriate
- that additional *'before'* and *'after'* break data should be collected and published
- that an alternative conceptual approach, based on failures being due to a combination of factors, needed to be developed
- to advise Water Loss Task Force members, and other followers of WLTF approaches, of the change in emphasis since the Leakage 2005 conference
- that the further work should be co-ordinated and published by the pressure management team of the WLTF

The alternative conceptual approach, described in more detail in this paper, was circulated as a Power Point presentation to Water Loss Task Force members in September 2006. Additional data were collected from 110 systems in 10 countries, and in a short article in Water 21 (Thornton & Lambert, 2006) the additional data were shown in the form of Table 1, together with the message that the N2 approach had been abandoned, and an alternative conceptual approach that was being evaluated.

Since the December 2006 Water 21 article, some encouraging (but limited) further work has been done (using data from Australia, Canada, Cyprus) to see if general qualitative predictions of reductions in break frequency can be made by comparing the *'pre-pressure management'* break frequency (on mains, per 100 km/year; on services, per 1000 services per year) with the assumed frequencies for infrastructure in good condition, used in the Unavoidable Annual Real Losses (UARL) formula.

A topic of obvious interest, for Utility managers in developing countries with poor infrastructure, and high break frequencies at comparatively low pressures, is whether pressure management can be effective in reducing new break frequencies in such circumstances. Data from large loss reduction projects in Malaysia and Brazil in this paper confirm this to be the case.. Additional data from a performance based NRW reduction project in Bahamas are shown in Fanner (2007)

The suppression of surges (pressure transients) is a key issue in controlling new break frequencies, and some initial results from Philadelphia Water Department (PWD) are presented, of the effect of a PRV on suppressing surges in a pumped distribution system by the use of DMA and PRV. This effect will be studied further by the WLTF PM team and updates will be provided as further data becomes available

## The Extended Data Set

An extended data set of 112 systems from 10 countries is summarised in Table 1. The following can be noted:

- *'before'* pressure (metres) ranges from 23 to 199, median is 57 and average 71
- % pressure reduction ranges from 10% to 75%, median 33%, average 37%
- % reduction in breaks ranges from 23% to 94%, median 50% , average 53%
- the data shows no significant difference between average % break reductions on mains and service connections

The data from Table 1 are also shown in Figure 1 as a plot of % reduction in pressure vs. % reduction in new break frequency, for mains and services together.

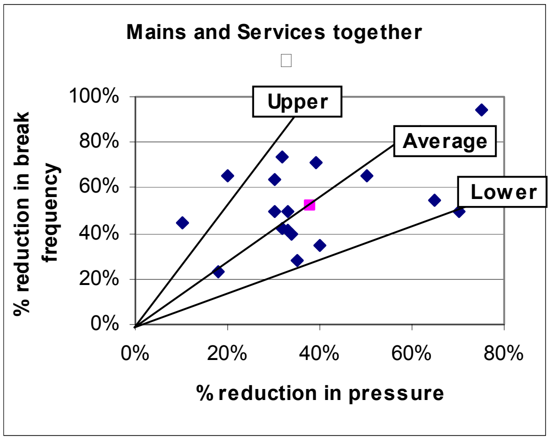
**Table 1** The influence of Pressure Management on new break frequency from 112 systems in 10 countries

| Country | Water Utility or System | Number of Pressure Managed Sectors in study | Assessed initial maximum pressure (metres) | Average % reduction in maximum pressure | Average % reduction in new breaks | Mains (M) or Services (S) |
|---|---|---|---|---|---|---|
| Australia | Brisbane | 1 | 100 | 35% | 28% | M,S |
| | Gold Coast | 10 | 60-90 | 50% | 60% | M |
| | | | | | 70% | S |
| | Yarra Valley | 4 | 100 | 30% | 28% | M |
| Bahamas | New Providence | 7 | 39 | 34% | 40% | M,S |
| Bosnia Herzegovin | Gracanica | 3 | 50 | 20% | 59% | M |
| | | | | | 72% | S |
| Brazil | Caesb | 2 | 70 | 33% | 58% | M |
| | | | | | 24% | S |
| | Sabesp ROP | 1 | 40 | 30% | 38% | M |
| | Sabesp MO | 1 | 58 | 65% | 80% | M |
| | | | | | 29% | S |
| | Sabesp MS | 1 | 23 | 30% | 64% | M |
| | | | | | 64% | S |
| | SANASA | 1 | 50 | 70% | 50% | M |
| | | | | | 50% | S |
| | Sanepar | 7 | 45 | 30% | 30% | M |
| | | | | | 70% | S |
| Canada | Halifax | 1 | 56 | 18% | 23% | M |
| | | | | | 23% | S |
| Colombia | Armenia | 25 | 100 | 33% | 50% | M |
| | | | | | 50% | S |
| | Palmira | 5 | 80 | 75% | 94% | M,S |
| | Bogotá | 2 | 55 | 30% | 31% | S |
| Cyprus | Lemesos | 7 | 52.5 | 32% | 45% | M |
| | | | | | 40% | S |
| England | Bristol Water | 21 | 62 | 39% | 25% | M |
| | | | | | 45% | S |
| | United Utilities | 10 | 47.6 | 32% | 72% | M |
| | | | | | 75% | S |
| Italy | Torino | 1 | 69 | 10% | 45% | M,S |
| | Umbra | 1 | 130 | 39% | 71% | M,S |
| USA | American Water | 1 | 199 | 36% | 50% | M |
| Total number of systems | | 112 | | | | |
| | | Maximum | 199 | 75% | 94% | All data |
| | | Minimum | 23 | 10% | 23% | All data |
| | | Median | 57 | 33.0% | 50.0% | All data |
| | | Average | 71 | 38.0% | 52.5% | M&S together |
| | | Average | | 36.5% | 48.8% | Mains only |
| | | Average | | 37.1% | 49.5% | Services only |

A simple interpretation, likely to give generally conservative predictions, is to assume that the % reduction in new breaks = BFF x % reduction in maximum pressure, where BFF is a Break Frequency Factor, this can be checked against the data in Figure 1.

- The average value of BFF for Mains and Services together from Table 1 is 52.5%/38% = **1.4**, so a line drawn through the data in Figure 1 with a slope of 1.4 gives an 'average' prediction

**Figure 1** Simple basis for predicting % reduction in breaks from % reduction in pressure



- An ‘Upper’ line, with a BFF of 2.8 (twice the average) encompasses all but two of the data points which give larger reduction in new break frequencies
- A ‘Lower’ line, with a BFF of 0.7 (half the average) encompasses all the data points which give smaller reductions in new break frequencies

## The Latest Conceptual Approach

### *Explaining the concept*

The latest conceptual approach currently being used by the Pressure Management Team of the WLTF, in attempting to develop an improved practical understanding of pressure/break frequency relationships, is shown in the following series of figures.

In Figure 2.1, the X-axis represents system pressure and the Y-axis represents failure rates. When a new system is created, mains and services are normally designed to withstand maximum pressures far greater than the range of daily and seasonal operating pressures for a system supplied by gravity. The system operates with a substantial factor of safety, and failure rates are low. Even if there are pressure transients in the system (Figure 2.2), the maximum pressures do not exceed the pressure at which increased failure rates would occur.

**Figure 2.1** New system supplied by gravity operates well within design maximum pressure

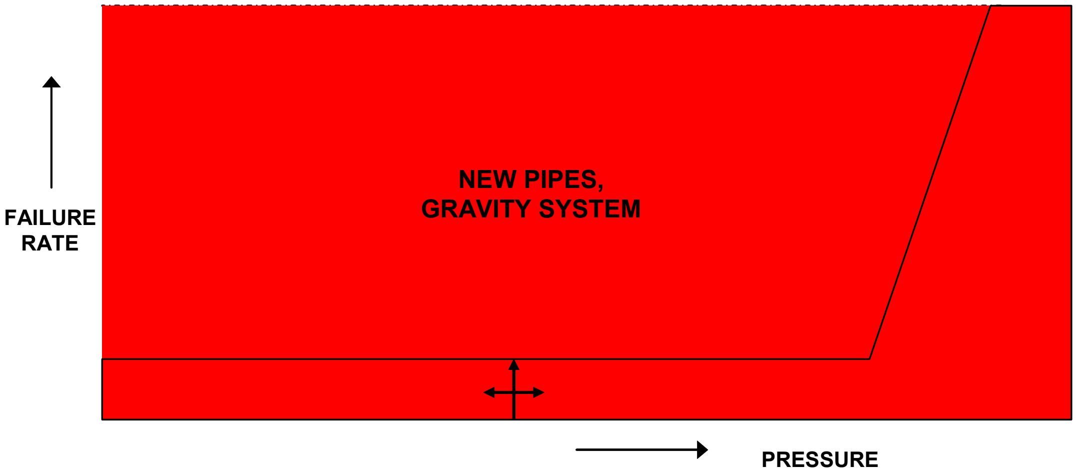
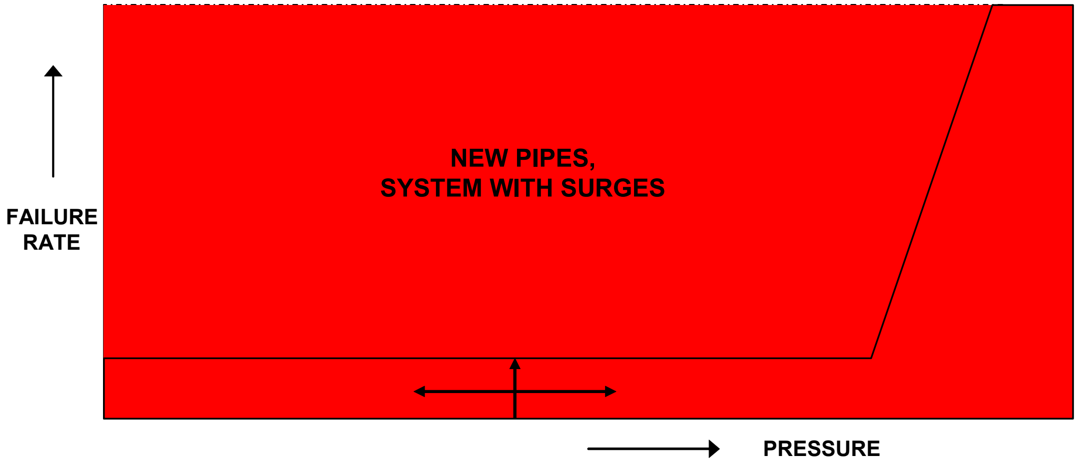
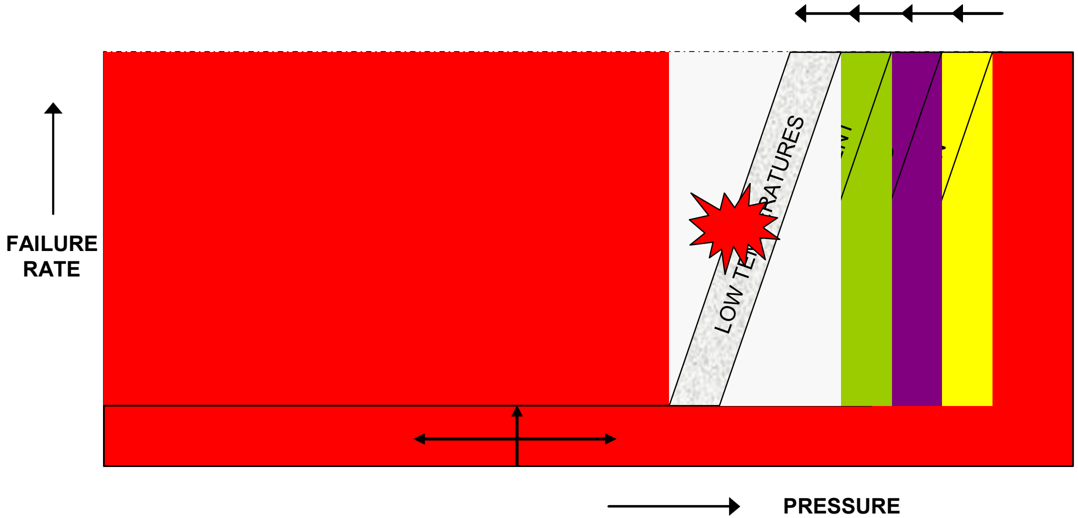


**Figure 2.2** New system with surges also operates well within design maximum pressure



As the years pass, adverse factors based on age (including corrosion) gradually reduce the pressure at which the pipes will fail (Figure 2.3). Then, depending upon local factors such as traffic loading, ground movement and low temperatures (which will vary from country to country, and from system to system), at some point in time the maximum operating pressure in the pipes will interact with the adverse factors, and break frequencies will start to increase. This effect can be expected to occur earlier in systems with pressure transients or re pumping, than in systems supplied by gravity.

**Figure 2.3** Combination of adverse factors (including surges) cause increased failure rates

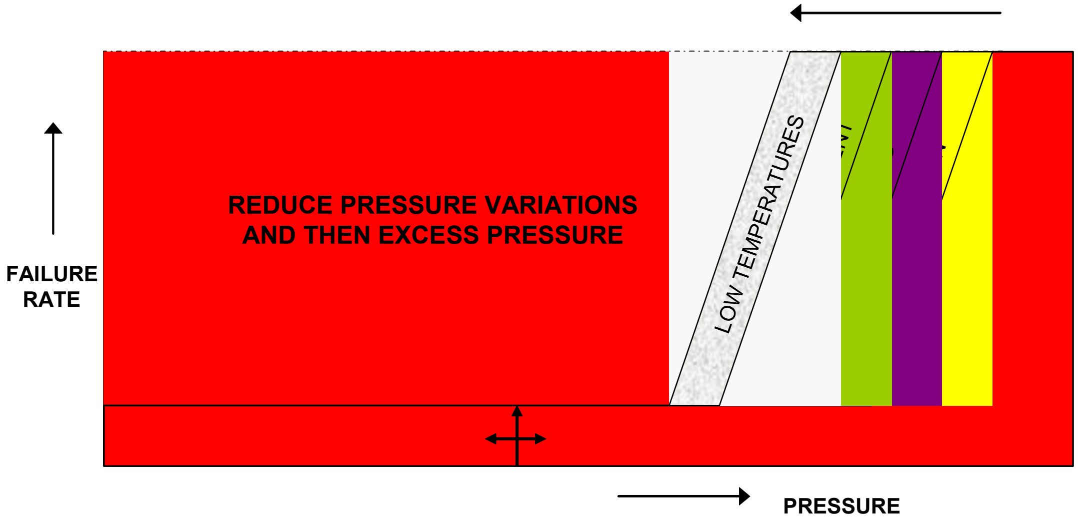


If the system is subject to surges or large variations in pressure due to changing head loss conditions, then introduction of surge control or flow or remote node pressure modulation may be expected to show a rapid significant reduction in the new break frequency. The average pressure in the system is unchanged, but the reduction of surges and large variations means that maximum pressures do not interact to the same extent with the adverse factors.

If there is excess pressure in the system at the critical point, over and above the minimum standard of service for customers, then permanent reduction of the pressure by installation of pressure management (PRV, sub-division of large Zones, etc) will move the range of operating pressures even further away from the pressure at which combinations of adverse factors would cause increased frequency of failure.

Figure 2.4) shows the effect of reducing surges and variations in pressure and then reducing excess pressure.

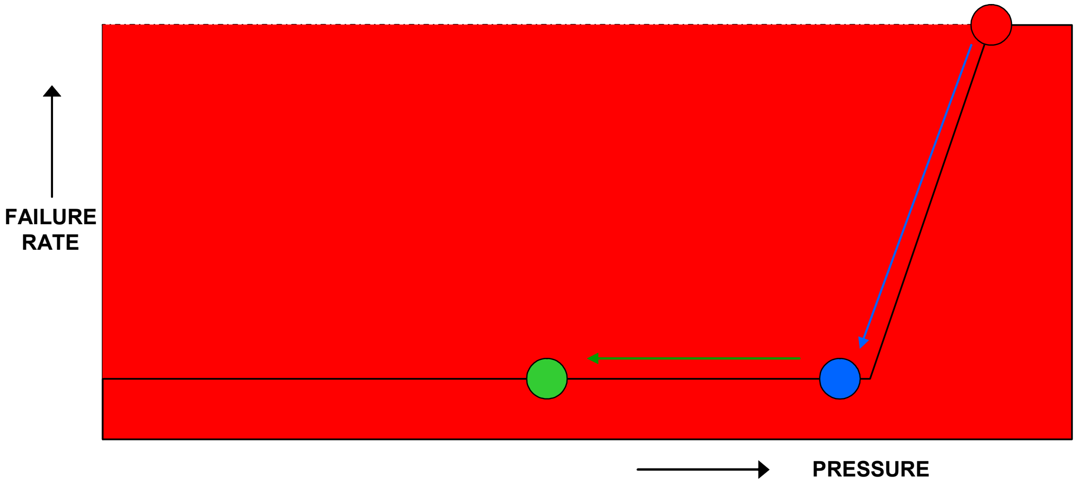
**Figure 2.4** Reduction of surges and variations and reducing excess pressure limits interaction with adverse factors and increases factor of safety



A hypothesis as to why mains and/or service connections in some systems show large % reductions in new break frequency with pressure management, but in others the % reduction is only small, can be proposed using this concept.

- If, before pressure management, there is already a relatively high break frequency (Red Point in Figure 2.5), then a relatively small % reduction in pressure may cause a large % reduction in new break frequency (towards Blue Point ).
- But if there is already a relatively low break frequency before pressure management (Blue Point in Figure 2.5), then any % reduction in pressure (from Blue Point to Green Point) should have little effect on new break frequency, but will create a greater factor of safety and extend the working life of the infrastructure.

**Figure 2.5** % reductions in break frequency influenced by initial break frequency



## The Straw that breaks the Camel’s back

### *Some international experiences*

Although some Utilities ascribe their high seasonal break frequencies to one particular cause (low temperatures, ground movement, traffic loading, corrosion etc), further investigation often seems to show that it is the occurrence of a higher pressure (added to the other adverse effects) that triggers many of the individual failures.

Most Utility engineers will have experienced situations of sudden increases in breaks when parts of their distribution system are subjected to excess pressure, due to events such as by-passing of a service reservoir, unauthorised opening of a boundary valve or PRV bypass, or a PRV failing in open mode. That pipe failures can be caused by surges from pumping or sudden valve closures is also well known, and failure rates in systems with intermittent supply have been identified as many times higher than would be expected from an equivalent system with continuous supply. There are also examples from Melbourne and in South Africa, where individual mains breaks in gravity systems have been identified as being due to operation of customers' equipment.

The interest of one of the authors in this topic was stimulated, some 10 years ago, by the casual observation of a Swiss Utility engineer to the effect that it was easy to predict when most of the breaks in his distribution system with metal pipes would occur – in the winter, overnight, when distribution pressures reached their maximum.

In Melbourne (Australia), the high seasonal peak in break frequency occurs at the time of maximum demand (in summer, around January), and has been locally attributed to ground movement, rather than any other reason. However, further investigation by a local Task Force member identified that most of the breaks actually occurred in the early hours of the morning, when system pressure was at its highest.

From the above examples, it is not surprising that identification and reduction of pressure transients and large variations, and of excess pressures, can be expected to reduce high break frequencies. So, in the case of pipe failures, to quote the famous proverb, high pressure – however brief - can often be *'the straw that breaks the camel's back'.* By identifying, reducing and avoiding surges, pressure variations and excess pressure in our distribution systems, we can influence the frequency of new breaks on mains and services. But is this general approach also effective in developing countries with high break frequency situations and relatively low pressures?

### *Brazil, Malaysia and Bahamas*

In a recent presentation (Paracampos 2007) Francisco Paracampos reported that in the central business unit of SABESP (the water utility of Sao Paulo, Brazil) he had observed that in the 180 Zones with PRV, break frequencies on mains and services were around 10 per km/year. However, in areas not covered by PRV, break frequencies were almost double at around 19 per km/year.

In Malaysia, in a system with high break frequencies throughout the year, SYABAS (the water utility for Selangor State) is setting up numerous pressure managed zones (PMZ). SYABAS has identified that most breaks occur at maximum pressures at night, and has recently evolved a policy of using fixed outlet pressure management to reduce new break frequency. In a sample of 34 PMZ with 224 km of mains, new mains break frequency has fallen from more than 300 per 100 km/year to 18 per 100 km/year. Although some of this data is of quite limited duration, and a longer period of comparison is needed to confirm these statistics, these results are nevertheless dramatic.

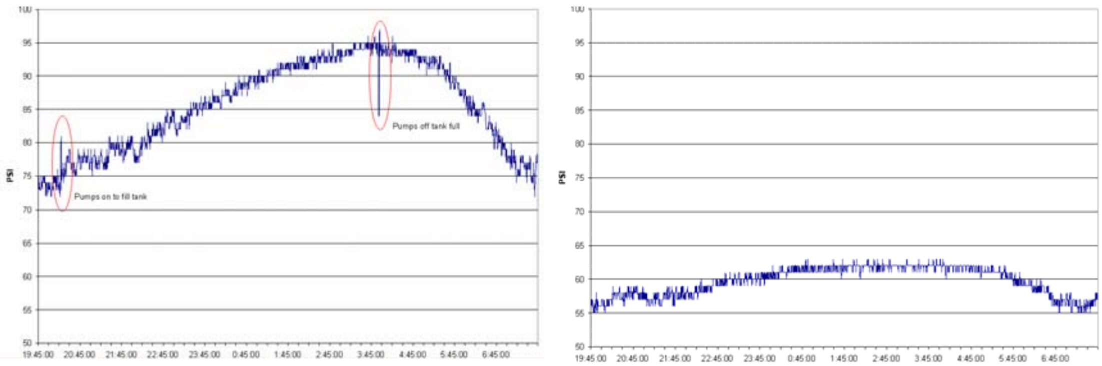
Data on changes in break frequency following pressure management, for a relatively low-pressure and high break frequency pumped system in the Bahamas, are discussed in Fanner (2007)

### *Influence of PRV on surges*

As part of a National AWWARF research program to identify suitable methods for North American utilities to employ for sustainable water loss reduction, Philadelphia Water

Department (PWD) installed a pressure managed DMA. In addition to impressive reductions in real loss volumes PWD noted that the DMA and PRV helped to damp out distribution transients caused by pumping changes (Figure 3) when a nearby water storage facility reached maximum and minimum water levels.

Figure 3 before and after control in DMA 5 shows distribution transients removed by PRV control



## What are the priorities now?

### *Encouraging Implementation*

Present knowledge of pressure/break relationships has similarities to the situation in the UK and Japan in the 1980's, when it had been clearly identified by field tests that leak flow rates in distribution systems were more sensitive to pressure than predicted by the *'square root'* relationship (flow varies with the square root of pressure). The reasons for the greater sensitivity to pressure were not understood, and research into this topic took another 15 years to reach a satisfactory practical conclusion (the FAVAD concept). However, inability to reliably predict results did not stop progressive Utilities from introducing successful pressure management schemes from 1980 onwards, with demonstrable reductions in leak flows particularly at night.

It appears to the authors that, while an increasing number of Utilities and national organisations are showing interest in the latest results of the WLTF pressure/break frequency studies, there is a reluctance to include any predictions of the financial benefits in calculations of payback period for pressure management schemes, until a reliable prediction method has evolved. This is surprising, because for most systems the short-term financial benefits of even a modest reduction in break frequency and repair costs will far exceed the financial benefit calculated only on the basis of the predicted reduction in leak flow rates, and significantly reduce the calculated pay-back periods. Also, calculations of economic leakage levels surely must now take account of the influence of pressure management (Fantozzi and Lambert, 2007)

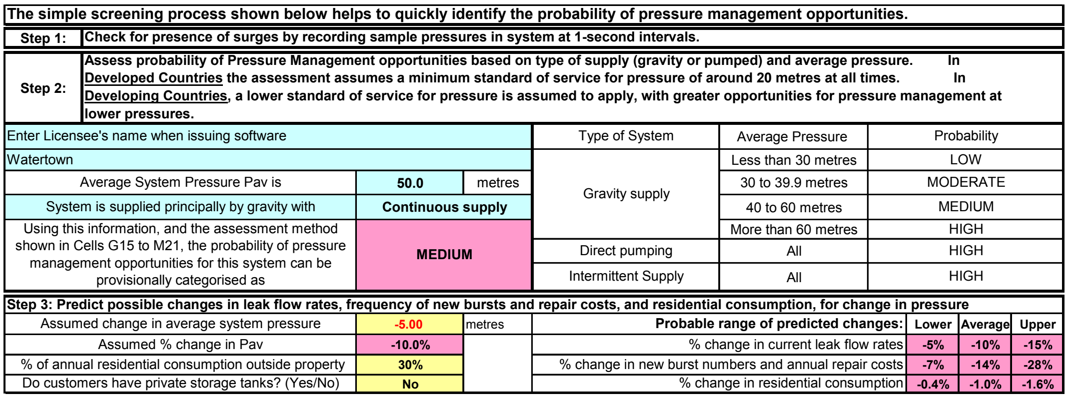
The authors recognise that it may take years of applied research to achieve predictions of pressure/break frequency for individual systems to the same degree of accuracy that FAVAD has achieved for pressure/leak flow rates and pressure/consumption relationships. The immediate priorities are therefore:

- to provide Utilities with a quick overview calculation of the probable range of outcomes of basic pressure management for individual systems, in terms of changes in leak flow rates, break frequencies and consumption
- to attempt separate predictions of changes in break frequency of mains and services, as average costs for repairs differ significantly.

*Quick Overview Calculations*

The free 'CheckCalcs' software (2007) uses a simple 3-step approach (Figure 4). By entering proposed change in average pressure (increase +ve, decrease -ve), together with '% of consumption outside property', and 'Yes' or 'No' for presence of private storage tanks, the software predicts the Lower, Average and Upper % changes in leak flow rates, new break frequencies and consumption, using FAVAD concepts and Figure 1. More detailed predictions can then be made, if required, using the 'PressCalcs' software.

**Figure 4** 'PMOpportunities' Worksheet from free CheckCalcs software



**The simple screening process shown below helps to quickly identify the probability of pressure management opportunities.**

| | |
|---|---|
| **Step 1:** | **Check for presence of surges by recording sample pressures in system at 1-second intervals.** |
| **Step 2:** | **Assess probability of Pressure Management opportunities based on type of supply (gravity or pumped) and average pressure. In Developed Countries the assessment assumes a minimum standard of service for pressure of around 20 metres at all times. In Developing Countries, a lower standard of service for pressure is assumed to apply, with greater opportunities for pressure management at lower pressures.** |

| | | | | | |
|---|---|---|---|---|---|
| Enter Licensee's name when issuing software | | | Type of System | Average Pressure | Probability |
| Watertown | | | Gravity supply | Less than 30 metres | LOW |
| Average System Pressure Pav is | **50.0** | metres | | 30 to 39.9 metres | MODERATE |
| System is supplied principally by gravity with | **Continuous supply** | | | 40 to 60 metres | MEDIUM |
| Using this information, and the assessment method shown in Cells G15 to M21, the probability of pressure management opportunities for this system can be provisionally categorised as | **MEDIUM** | | | More than 60 metres | HIGH |
| | | | Direct pumping | All | HIGH |
| | | | Intermittent Supply | All | HIGH |

**Step 3: Predict possible changes in leak flow rates, frequency of new bursts and repair costs, and residential consumption, for change in pressure**

| | | | | | | |
|---|---|---|---|---|---|---|
| Assumed change in average system pressure | **-5.00** | metres | **Probable range of predicted changes:** | **Lower** | **Average** | **Upper** |
| Assumed % change in Pav | **-10.0%** | | % change in current leak flow rates | **-5%** | **-10%** | **-15%** |
| % of annual residential consumption outside property | **30%** | | % change in new burst numbers and annual repair costs | **-7%** | **-14%** | **-28%** |
| Do customers have private storage tanks? (Yes/No) | **No** | | % change in residential consumption | **-0.4%** | **-1.0%** | **-1.6%** |

## Separate Predictions of Changes in Break Frequency for Mains and Services

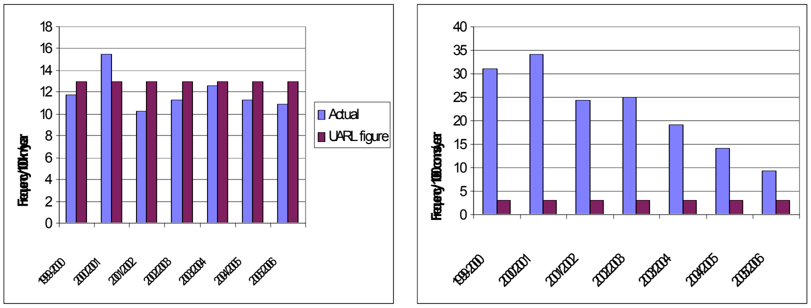
The authors have started to test the simple predictive approach shown in Figure 2.5, which uses the break frequencies on mains and services *'before'* pressure management to indicate whether the % reductions in break frequency are likely to be relatively low or high. The break frequencies used in the Unavoidable Annual Real Losses (UARL formula) are used as an existing WLTF *'low'* standard for comparison, these are as follows:

- for mains and private pipes, 13 breaks/100 km/year
- for services, main to property line or curb-stop, 3 breaks/1000 service cons/year

**Wide Bay Water, Australia**: this distribution system (19,000 services, 690 km mains) is being progressively sectorised with flow modulated pressure managed zones. Surges have been identified and suppressed. Average pressure has been reduced by 16%, from 63 to 53 metres. Previous mains break frequency was close to UARL frequency, so no significant change occurred (Points B to C on Fig 2.5). However, previous service pipe break frequency was 12 times the UARL frequency, and a substantial reduction would be expected (Points A to B on Fig 2.5), and was observed. See figures 5.1 and 5.2

**Figures 5.1 and 5.2** Wide Bay Water: changes in break frequency following pressure management

**Figure 5.1**: Mains **Figure 5.2**: Service connections



**Halifax Regional Water Commission (Canada),** In the Dartmouth pressure managed zone (3158 services, 59 km of mains), fixed outlet pressure management was replaced by flow modulated pressure management. Maximum pressure (at night) was reduced by 20% from 78.9 to 64.4 metres. Mains break frequency, initially 3 times the UARL frequency, would be expected to reduce, and did, to 1.5 times the UARL frequency. In contrast, service pipe break frequencies prior to flow modulation were very low (below the UARL frequency), and showed no observable reduction in frequency as predicted.

**Lemesos (Cyprus),** Changes in break frequency data following establishment of smaller zones (Charalambous, 2005) were re-analysed. Initial mains break frequency was 2.7 times, and initial service break frequency 11 times, the UARL frequencies. Significant reductions in both types of breaks would be expected (and occurred) when average zone night pressure reduced by 32% from 52.5 to 38.5 metres. The actual reductions (45% and 40% respectively) were close to the average values (32% x 1.4) predicted from Fig.1.

## Conclusions

Table 1 clearly demonstrates that reductions in new break frequencies following pressure management can be so substantial that they demand attention from progressive Utilities.

The conceptual approach outlined in Figures 2.1 to 2.5 appears to be broadly consistent with general international experience.

Separate predictions of changes in break frequency for mains and services, based on comparison with break frequencies used in the UARL formula, appear to be a promising approach.

It is hoped that Utilities will be encouraged by this work to implement pressure management where appropriate and report the results.

The WLTF Pressure Management team will continue to analyze data as it becomes available and publish results periodically.

Longer term implications and benefits for infrastructure management and energy management will also be future important topics for the Pressure Management Team

## Acknowledgements

The utilities and WLTF members, that contributed data and to Dave Pearson, Stuart Trow, John Morrison and Orlando Figuerdo for assisting in development of the latest conceptual approach.

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