Evaluation of
Potential Best Management Practices
-
Distribution System Pressure Manaagement

Prepared for

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DISCLAIMER

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Table of Contents

NOTE: For a full introduction to the
Council's Potential Best Management Practice (PBMP) process,
refer to the Year Three report that details the purpose and
status of that process since its inception in 2004:
http://www.cuwcc.org/products/pbmp-reports.aspx

Distribution System Pressure Management

Background

Pressure regulation comes in many forms: surge control, level control, pressure relief, pressure reduction or pressure sustaining. Pressure reduction, or pressure management (PM) as it is commonly referred to, is a method that is commonly applied to water distribution networks by leakage reduction practitioners to reduce water losses. A suite of tools exists to actively reduce water loss. Of these tools, PM has been referred to as "the preventative method par excellence"[1]. It is the only tool that can be deployed to existing infrastructure which reduces all types of leakage (background, reported and unreported). In some countries, notably Japan and the UK, it has been recognized for over 20 years that effective management of pressures is the essential foundation of effective leakage management. However, recognition of this fact is not universal[2].

PM reduces leakage levels in two ways:

a) Reducing the flow rate through existing leaks

b) Reducing the frequency of new breaks

The frequency of new breaks is reduced because PM reduces average and maximum pressures, reduces diurnal pressure variations and can filter out pressure transients.

Pressure managed areas (PMA) are discreet zones of the network that have pressure reducing valves (PRV) at the inlets. The PRVs can have a basic fixed outlet pressure control or can be upgraded to have controls applied that typically modulate output pressure based on time, pressure, flow or remote control. A high efficiency PRV control is based on flow modulation so that during the night, when demand typically decreases and pressure increases, the pressure can be reduced further. Maximum leakage levels typically occur at night because of higher system pressures.

Pressures cannot be reduced arbitrarily. Minimum levels of service to customers as well as fire fighting capacity from fire hydrants must be maintained.

PMAs are distinct from District Metered Areas (DMA) in that a DMA can function on a temporary basis. A DMA is a well-established leakage management method for flow measuring a zone covering around 2,000 customer connections. A DMA can be permanent or can be periodically established to assess inflow and therefore get a snapshot of the leakage level within a zone. When an area of higher burst frequency and higher pressure is established as a PMA, then it should remain under the lower pressure regime as the consequences of breaching the zone and introducing higher pressures, albeit temporarily, will likely lead to a spate of bursts and certainly higher leakage levels. Once the PMA is established, it should remain so[3]. For critical PRVs,

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[1] Thornton & Lambert, 2007: "Pressure management extends infrastructure life and reduces unnecessary energy costs"

[2] Julian Thornton, IWA Task Force Water Loss: "Managing leakage by managing pressure: a practical approach"

[3] When scoping potential pressure managed schemes it should be remembered that scope often exists within a larger pressure district to introduce sub-divisions. This means that even if the district critical node is already at the minimum

redundancy may be required in the form of a back-up PRV, on by-pass, so that if the primary PRV is taken off line, say for servicing or repair, the reduced pressure regime into the zone can still be maintained.

In addition to leak reduction, pressure management will also reduce some types of customer consumption[4] and may therefore negatively impact revenue[5]. Although this effect can be a disincentive to pressure management, it can also be positive in terms of managing peak demands.

There are several factors that can contribute to breaks in the distribution network such as low temperatures, ground movement, traffic loading and corrosion, but further investigation often seems to show that it is the occurrence of a higher pressure, added to the other adverse factors, that triggers many of the individual failures. This has led higher pressures to be characterized by practitioners as "the straw that breaks the camel's back".

Water Savings

As noted earlier, PM reduces leakage through reduced flow rates and reduced break frequencies. Forecasting water savings is very situation-specific as characteristics such as pipe material, local break frequency and local pressures are key factors in the forecast. This illustrates that PM is a tool to be applied to targeted areas once robust feasibility analysis has been completed, thus ensuring deployment in areas where savings are maximized against expenditure.

It took 15 years of research and analysis for a satisfactory model to be created for forecasting water savings through reduced flow rates. This is the FAVAD[6] (Fixed and Variable Area Discharge) power law concept. It is only in the last few years that a concept for forecasting reductions in break frequencies has been developed. What has emerged is a qualitative prediction of reductions in break frequency with the assumed frequencies for infrastructure in good condition[7]. The FAVAD concept is also used to model consumption reduction. A detailed description of the savings forecast models can be found in the Technical Appendix.

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level of service, sub-divisions can be created in the higher-pressure areas and pressure reduced. This leaves the critical node under the existing pressure regime. Existing PRVs can be very readily optimized by upgrading controls. In this situation it is the pilot system (plumbing external to the PRV body) only which requires retrofitting for additional control measures with the body of the PRV remaining unaltered.

[4] Reduced system water pressure may reduce irrigation system flows and, very importantly, will reduce or even eliminate tank-type toilet leakage where pressure-sensitive ballcock type toilet fill valves are installed. Experience has shown that the typical system pressure increases in the early morning hours causes fill valves to open, increasing the water level in toilet tanks to where spillover into the overflow tube occurs. All of this water flows directly to drain.

[5] However, the reduction of leaks can result in reduced operating costs sufficient to offset the revenue reductions from less customer consumption.

[6] Developed by John May, 1997

[7] Thornton & Lambert 2007: Pressure management extends infrastructure life and reduces unnecessary energy costs.

Forecasting Water Savings for a Zone

To forecast savings from water loss reduction potential for a zone, actual data is required on:

- Leakage levels
- The FAVAD power exponent N1 for the zone (used in pressure and leakage relationship)
- Consumption levels
- The FAVAD power exponent N3 for the zone (used in pressure and consumption relationship)
- Current burst frequency, compared with unavoidable burst frequency (generates the BFF)
- Pressure profiles

To be able to undertake a simplified forecast of water savings, without actual zone data, a basic method that could be applied would be to take actual consumption and real loss rates and then apply average characteristic in terms of:

- Typical N1 = 1
- Typical N3 = 0.2
- Average international Burst Frequency Factor (BFF) = 1.4
- 10% reduction in maximum pressure typically achievable
- Applying a N1 of 1 means that a 10% reduction in pressure would yield a 10% reduction in leakage (linear relationship).
- Applying a N3 of 0.2 means a 10% reduction in pressure would yield a 2% reduction in consumption.
- Applying the average BFF of 1.4 would mean that a 10% reduction in maximum pressure would lead to a 14% reduction in current break frequency.

This method of using "typical" characteristics must be treated with caution. Even when applying best practice methods and utilizing system-specific data, results will still exist within error bands. As such, applying "typical" (rather than system-specific data) characteristics obviously increases error bands significantly.

Case Studies in Water Savings

The following projects are presented as evidence of actual water savings achieved through PMA implementation in North America. Three of the schemes were presented by AWWA Research Foundation[8] and one is from a project implemented by Veritec Consulting Inc.[9] The characteristics of each PMA and the actual water savings are listed in Table 1.

[8] Fanner, Sturm, Thornton & Liemberger: AwwaRF Leakage Management Technologies 2007

[9] www.cla-val.ca/announcement/CITYOFTORONTOPMARTICLEVERITEC.PDF

Table 1. Case Studies – PMA Characteristics & Actual Water Savings

	El Dorado Irrigation District	Philadelphia Water Department
	Existing PRV upgraded to flow modulation	New fixed outlet pressure PMA created from open grid network
No of inlets (no.)	1	2
No. of service connections (no.)	444	2,465
Mains length (km)	27	25
Original average pressure (psi)	109	99
New average pressure (psi)	NA	66.4
Percentage reduction in pressure (%)	NA	32.9
Annual water savings from Pressure Management (m3/yr)	23,579	133,152
Annual water savings from Pressure Management (AFY)	19.1	108.0
Percentage real loss reduction (%)	9.9	29.4
Lifetime water savings (15 years) from Pressure Management (acre-feet)	286.8	1,619.5
	Halifax Regional Water Commission	**City of Ontario – East York Pilot**
	Existing DMA upgraded to flow modulated PMA	Open grid network turned into flow modulating PMA
No of inlets (no.)	2	3
No. of service connections (no.)	3,158	7,290
Mains length (km)	59	52
Original average pressure (psi)	88	58
New average pressure (psi)	71.9	50
Percentage reduction in pressure (%)	18.3	13.8
Annual water savings from Pressure Management (m3/yr)	230,242	62,780
Annual water savings from Pressure Management (AFY)	186.7	50.9
Percentage real loss reduction (%)	30.1	27.9
Lifetime water savings (15 years) from Pressure Management (acre-feet)	2,800.3	763.6

NOTE: The above projects were data logged for flow and pressure pre- and post-commissioning in order to analyze the performance of the PMAs and determine the water savings. The data was recorded over a period of days and the results extrapolated here to give annual figures.

Product and Program Costs

As with the water savings described in the previous section, product and program costs are very situation-specific. Scoping and designing a PMA is not a "one size fits all" solution. Precise costs for establishing PMAs vary widely depending upon the following key characteristics:

- The number of PRVs required to cover inlets to the zone (multiple inlets can increase available fire fighting capacity)
- Availability of existing chambers that can be retrofitted to accept a PRV (chamber retrofit is often cheaper than new chamber construction)
- Availability of existing PRVs that can be retrofitted with additional advanced controls
- The type of control applied (e.g. fixed outlet pressure, time modulated or flow modulated)
- Depth of water mains driving new chamber construction cost

In North America, a PMA could be initially established for a unit cost estimated to be within the range of $20,000 to $200,000 for mains lengths approximately 30 to 100 km. The cost components of PMA implementation are as follows:

Engineering Resource Costs

- Feasibility Study
- Design
- Commissioning
- Ongoing maintenance

PRV Station Civil Engineering Costs

- New chamber construction or existing chamber retrofit
- PRV and pipe work construction
- Redundancy requirements

PRV Station Electrical and Communication Costs

- Data logging
- SCADA[10] connectivity (optional)
- Modulation control (optional)

Hardware Maintenance

- The hardware installed will require maintenance; reactive or scheduled pro-active

In terms of the civil engineering, electrical and communication costs, a number of different options exist. If an existing chamber can be utilized for the new PRVs, then civil construction

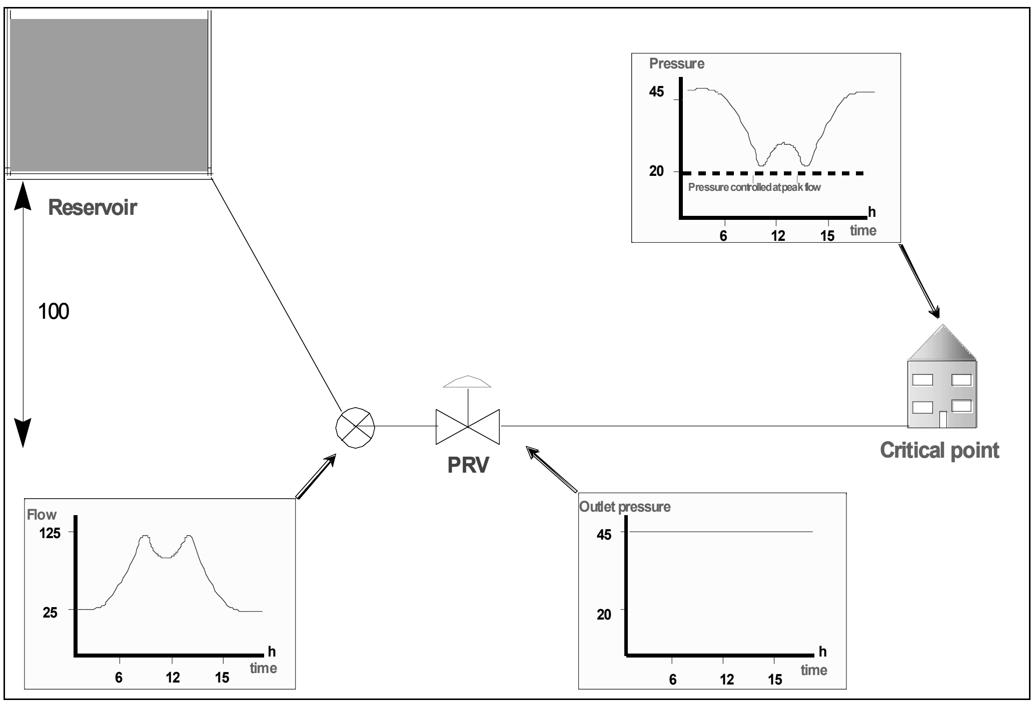
[10] Supervisory Control And Data Acquisition

costs will be greatly reduced. The level of integration into the utilities communication networks will need to be determined in terms of telemetry and SCADA. For the types of PRV control, the four most common approaches have been described in detail below to show their characteristics and where they are applicable.[11]

1. Fixed outlet control

This first option is simply a conventional PRV that is used to provide continuous pressure at the inlet(s) of a supply zone (outlet(s) of the valve(s)). This type of pressure reduction is efficient where there is no significant head loss in the system and where the demands are relatively stable all year round. A representation of this is shown in Figure 1 below.

Figure 1. Fixed Outlet Control



[11] AWWA M36 Manual of Practice, Water Audits and Loss Control Programs, 2009

2. Time modulated control

The time-modulated controller is the simplest form of advanced pressure reduction, which allows multi-set outlet pressures; it also requires the least capital outlay. It is essentially a timing device that can be retrofitted to any PRV pilot system to reduce the outlet pressure during certain times of the day. It is a very simple and compact device that can accommodate up to four period settings over a typical 24-hour cycle between two pressure settings: a high level dictated by the PRV itself and a low level as set on the controller. This is a simple but effective method of reducing pressures in systems where there is a consistent daily demand pattern. Alternately, two or three pilots can be set up on a PRV and a timer and solenoid valve assembly re-routes flow through one or the other pilots depending on the time of day.

The optimal application of the time-modulated controller is to reduce pressures during off-peak periods when system pressures tend to be higher than required. This, then, reduces the average zone pressure at times when system breaks are most likely to otherwise occur.

The largest disadvantage of time-modulated controllers concerns the maintenance of system fire-fighting capability. This controller cannot react to an increase in demand caused by a fire-fighting effort downstream of the PRV, however hydraulic solutions exist to bypass the controller in these cases. Care must be taken to not over-reduce pressures, thereby causing cavitation in the PRV; hydraulic speed controls should be carefully set to ensure that the valve neither opens nor closes too fast, causing surge in the system.

3. Flow modulated control

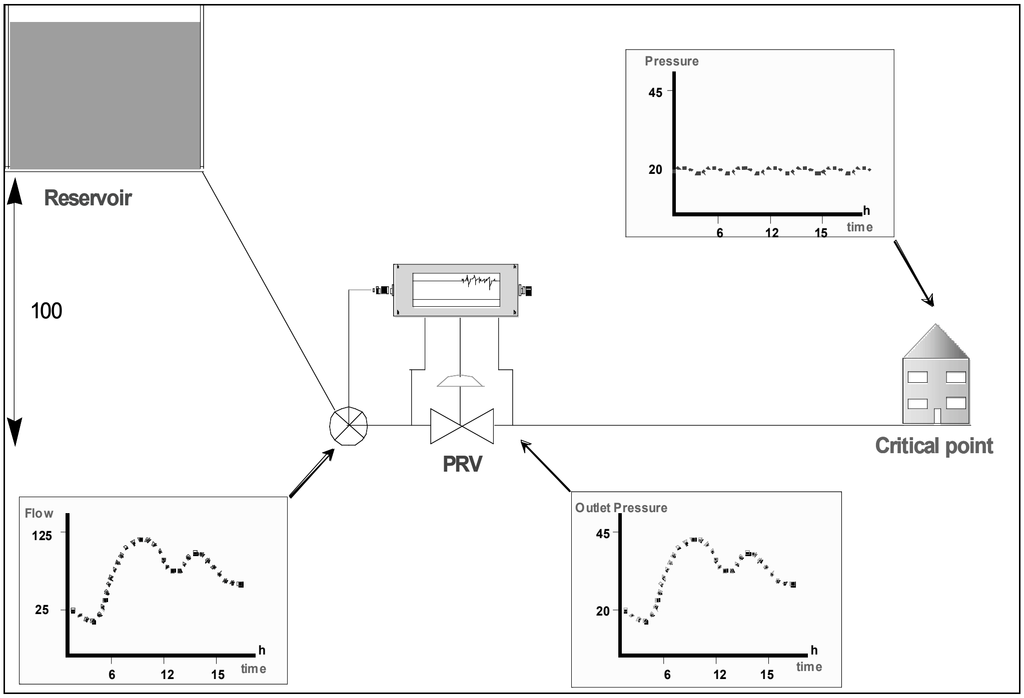
The third and more complex controller is the flow-modulated controller, which provides greater flexibility and control than that offered by the time-modulated controller, albeit at a greater cost.

The flow-modulated controller will modulate the downstream pressure of a PRV in accordance with the demand being placed on the system. During peak demand periods, the maximum pressure as dictated by the PRV will be provided, while during off-peak periods the downstream pressure will be reduced to minimize excess pressure on the system, thereby reducing losses through leaks. This type of controller can be programmed to modulate an even pressure at the remote or critical node, or at the average zone pressure (AZP) point (as shown in Figure 2).

This type of controller combats the system head loss throughout the day. It should be remembered that most of the breaks occur on the service lines where pressures are most affected by head loss. Usually the trunk or feeder mains are stronger and can accept the modulated pressure without adverse effects. However, in cases where the trunk mains are weak (such as with asbestos cement pipe with poor hydraulic couplings), care should be taken to modulate to the AZP point, thereby reducing the effect of changing pressures on the trunk line.

Controls allow the operator to limit the speed of the response to the system demand changes and the hydraulic or pneumatic pulse, which is sent to the pilot adaptor to initiate the change in pilot setting.

Figure 2. Flow Modulated Control



Operators must set these controllers properly to ensure that the valve sets do not hunt and actually create more pressure transients in the system[12]. The operator can check if the controller is operating correctly by logging the outlet pressure of the valve at very short intervals of one second. The true profile of the valve outlet pressure will be seen as opposed to an average outlet pressure over the normal (15 minute) logging period.

4. Remote node pressure control

Remote node pressure control involves the use of a controller and a remote pressure logger, which is located at either the critical node or the AZP depending on the regime of pressure reduction desired. The controller is designed to maintain a constant pressure at the logger by modulating the outlet of the valve(s) accordingly. Communications are undertaken either by radio or telephone line or, more recently, by GSM connections[13]. The latter form of control is probably the most effective and safe approach to advanced pressure reduction and, with recent communications advances allowing the use of low cost GSM loggers, is not really more cost prohibitive than the above option.

Table 2 summarizes the characteristics of the different methods of control described above. It is important to select the most appropriate form of pressure control for specific applications, which involves taking the available budget, projected savings and technical capabilities of field staff into account.

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[12] A scenario where a PRV is frequently modulating its outlet pressure to meet the target outlet pressure, however, it is happening in such a way that a steady output pressure is not achieved; rather, it ends up oscillating. This is termed “hunting”.

[13] GSM (Global System for Mobile Communications: originally from *Groupe Spécial Mobile*) is the most popular standard for mobile telephony systems in the world. In this case, the GSM network is used here to transmit communications with the valves.

Table 2. Summary of Different PRV Control Characteristics

Form of Pressure Control	Description	Cost	Water Loss Reduction Efficiency	Complexity to Maintain and Operate
Fixed Outlet Pressure	Basic PRV	Lower	Lower	Lower
Time Modulated	PRV outlet pressure varied according to time	Moderate	Moderate	Moderate
Flow Modulated	PRV outlet pressure varied according to in zone demand	Higher	Higher	Higher
Remote Node Pressure Control	PRV outlet pressure varied according to monitored pressure in the zone	Higher	Higher	Higher

In the case of PMA program implementation costs, the case studies are drawn on again here to illustrate:

El Dorado PMA Cost

Capital cost ($)	13,000
Annual maintenance ($/yr)	5,000
Lifetime cost (15 years) ($)	88,000

Philadelphia PMA Cost

Capital cost ($)	174,000
Annual maintenance ($/yr)	10,000
Lifetime cost (15 years) ($)	324,000

Halifax PMA Cost

Capital cost ($)	180,000
Annual maintenance ($/yr)	10,000
Lifetime cost (15 years) ($)	330,000

Toronto - East York PMA Cost

Capital cost ($)	163,800
Annual maintenance ($/yr)	15,000
Lifetime cost (15 years) ($)	388,800

Cost Effectiveness

Reduced Leak Flow Rate - Establishing the Cost/Value of Water Saved

For a pressure management scheme, the savings relating to reduced leak flow rate is dependent upon the value placed on the water being saved. Defining the appropriate value of water is therefore a pre-requisite to be able to undertake a cost-benefit analysis.

Reduced Burst Frequency

Reduced repair costs can be significant as a result of reduced burst frequencies. A higher initial burst frequency factor (BFF) will yield a greater reduction in repair costs through reduced pressure. While this will certainly be available in some zones, in others, low initial BFF's will mean that little potential for reducing burst frequency and repair costs will exist.

Reduced Consumption

Reduced consumption has a negative impact on PM's cost effectiveness since revenue is reduced[14]. Where water efficiency measures are required, those measures will only save water by reducing consumption (revenue water), whereas pressure management will mainly reduce leakage (non-revenue water) with some reduction in consumption as well.

Case Studies – PMA Cost Benefit Analysis

To look at costs and benefits, the case studies are drawn on again. A true cost-benefit analysis, with the payback period as a useful performance indicator, will take into account the value of water saved, an offset for revenue reduction from reduced consumption, and an element for the decrease in repair costs from reduced burst frequencies. In the case studies mentioned above, no consumption reductions were recorded (although they were presumed to occur) and information was not available on changes in burst frequencies. The payback period uses the capital costs against the value of water saved. With the high demand for water in California from finite resources, this analysis applies the average billed value of water delivered by each of the utilities in the case studies to run the payback period for each case study.

[14] This occurs only in areas where water to the customer is metered.

El Dorado PMA Cost to Benefit & Payback Period

Capital cost per acre foot of water saved ($/AF)	45.3
Whole life cost per acre foot of water saved ($/AF)	306.9
Payback period on capital spend vs retail value of water (yr)	1.5

Philadelphia PMA Cost to Benefit & Payback Period

Capital cost per acre foot of water saved ($/AF)	107.4
Whole life cost per acre foot of water saved ($/AF)	200.1
Payback period on capital spend vs retail value of water (yr)	1.4

Halifax PMA Cost to Benefit & Payback Period

Capital cost per acre foot of water saved ($/AF)	64.3
Whole life cost per acre foot of water saved ($/AF)	117.8
Payback period on capital spend vs retail value of water (yr)	3.9

Toronto - East York PMA Cost to Benefit & Payback Period

Capital cost per acre foot of water saved ($/AF)	214.5
Whole life cost per acre foot of water saved ($/AF)	509.2
Payback period on capital spend vs retail value of water (yr)	4.3

California Potential

The most appropriate method available to assess the potential for water savings for California is to pro-rate the findings from available studies[15] already conducted for North American cities. Population has been selected as the best available surrogate for an in-depth (and costly) investigation to establish Californian infrastructure performance and characteristics. California's estimated population in 2009 was approximately 37 million persons[16]. A detailed water audit and leak detection program involving 47 Californian water utilities found an average system loss of 10 percent and a range of losses from 30 percent to less than 5 percent of the total water supplied by the utilities[17]. The average California losses of 10 percent can be seen in the table below to be consistent with the studies used.

The method applied to forecast the costs and savings to comprehensively implement and optimize pressure management across the state of California (over the equipment's expected lifetime of 15 years) was to use preliminary data from three "Scope for Pressure Management Studies" undertaken and currently underway for cities in North America. Each city's water distribution network was assessed for its component leakage levels, burst frequencies, leak repair costs, consumption reductions, system pressures and penetration of existing PRVs. From the preliminary results of these studies, the average capital expenditure required per one million of population was calculated. Also, the average forecast water savings per one million of population was calculated. These data were then extrapolated to the state of California's population of 37 million. Annual maintenance costs were generated based on the coverage of PRV stations required ($5,000/PRV/yr). The results are shown in Table 3.

Table 3. Forecast of Cost Benefit of Pressure Management for California

	Population	Real Losses as % of Water Supplied	PM Water Savings Potential (new schemes & optimization of existing schemes) (ML/yr)	Whole life savings over 15 years (Acre-Feet)	Forecast Capital Spend ($K)	Main-tenance over lifetime of15 years ($K)	Whole life cost for 15 years ($K)	Whole Life Cost Benefit ($/Acre-Feet)
City A	1,019,942	13%	2,647		7,200			
City B	815,157	13%	1,671		5,280			
City C	2,480,000	9%	4,802		9,000			
California	36,961,664	10%	81,120[18]	986,622	211,600	10,349	221,949	225

[15] The studies for the three cities (Toronto, Calgary, and Ottawa) are not yet completed and, therefore, are not available for public distribution. Nor is there any assurance that they will be made publicly available by those cities once completed.
[16] US Census Bureau
[17] California Department of Water Resources: www.water.ca.gov/wateruseefficiency/leak/
[18] 81,120 ML/yr water savings is equivalent to 65,775 AFY, or 32,448 Olympic sized swimming pools per year.

This analysis has been performed on a calculated basis and is not based on the specific California infrastructure characteristics and performance analyses that would be required for detailed scope of pressure management assessments. Caution must therefore be applied to the results. Wide error bands around the results are appropriate.

The table above concludes that 81,120 ML/yr at $211.6M, with maintenance costs included, is equivalent to $225/AF of water saved. Referring back to the information from the case studies shown in the Cost Effectiveness section, the average cost from those study schemes, with maintenance costs included, was calculated at $284/AF. Therefore, the cost benefit range for California PMA schemes should be generally forecast as within the range of $225-284/AF over the expected lifetime.

It should be noted that implementing and maintaining PMAs is a task requiring skilled professionals to assess, prioritize and design them. For predicted savings to be realized, the operability of the PMAs must be established and maintained. As such, skilled utility operational staff must be engaged from the onset so that PMAs are effective and sustainable.

TECHNICAL APPENDIX

Reduced Leakage Flow Rates

The fixed and variable area discharge (FAVAD) power law shown below utilizes the exponent N1 in the relationship between pressure and leakage. N1 generally varies between 0.5 and 1.5 but can be as high as 2.5.

$$\frac{L_1}{L_0} = \left(\frac{P_1}{P_0}\right)^{N1}$$

C_0 = Consumption before PM C_1 = Consumption after PM
P_0 = Pressure before PM P_1 = Pressure after PM
N3 = Power law exponent in pressure consumption relationship

Small undetectable leaks at joints and fittings (background leakage) as well as larger leaks and bursts on flexible pipes typically have N1 values around 1.5, and have variable discharge areas. Detectable leaks and bursts on rigid pipes normally have N1 values close to 0.5 and have fixed discharge areas. In any given system the overall N1 will be an aggregation of the individual leak N1 discharge paths from the various different types of leaks (split, shear, hole) on the various pipe types (rigid, non-rigid). With infrastructure information on the percentage of rigid and non-rigid pipes within a system a fist pass weighted average N1 value for the system can be estimated (rigid pipes N1 = 0.5, non-rigid pipes N1 = 1.5) and the relationship between pressure and leak flow rates modeled using FAVAD. For systems with mixed pipe material types a N1 of 1 may initially be applied. Field measurements can be deployed to better establish more robust N1 values. The higher the N1 value the greater the benefits from pressure management will be.

The most concise paper on this topic is by the IWA Water Loss Task Force: Water 21 – Article No. 3[19]

Reduced Customer Consumption

The same FAVAD concept is used for the relationship between pressure and consumption, but a different exponent N3 is used.

$$\frac{C_1}{C_0} = \left(\frac{P_1}{P_0}\right)^{N3}$$

L_0 = Leakage before PM L_1 = Leakage after PM
P_0 = Pressure before PM P_1 = Pressure after PM
N1 = Power law exponent in pressure leakage relationship

In the same way that the leakage exponent N1 varies depending on the characteristics of the discharge path, the consumption exponent N3 varies depending on the characteristics of the consumption (its discharge path and potential fixed volume requirement). Under a change in pressure a toilet re-fill profile will behave differently to a lawn irrigation profile. The overarching categories for consumption have been classified as indoor use and outdoor use. Indoor use tends to be generally inelastic (N3i tending towards 0) and outdoor use is more elastic (N3o generally in the range 0.5 - 0.75). Supply pipe leakage and plumbing losses are considered consumption as they are within the property boundary. So the consumption power law exponent N3 is influenced by the components of consumption and their discharge paths and discharge volumes. Consumption will contain an element of customer side leakage. As a first

[19] Julian Thornton: Managing Leakage by Managing Pressure – A Practical Approach

pass a reasonable average N3 to use would be 0.2[20], which assumes outdoor use is 40% of total consumption and customer side leakage is a small percentage of total consumption.

A small California study was undertaken to investigate reducing consumption through pressure reduction[21]:

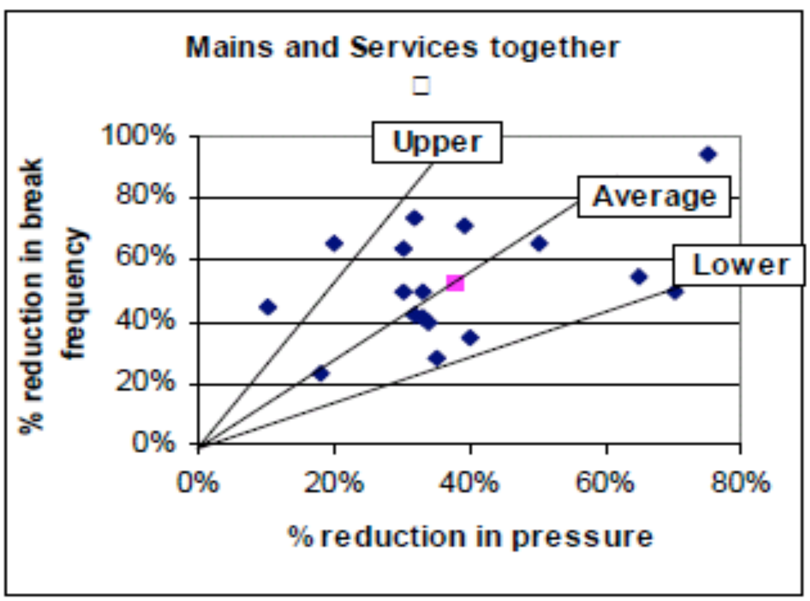
The IWA Water Loss Task Force, Pressure Management Team, continues to test and analyze data on this subject with tests ongoing on the components of consumption to establish component N3 values.

Reduced Break Frequencies

In order to predict the available % break frequency reduction relating to % reduction in pressure a Break Frequency Factor (BFF) needs to be established. This accounts for the severity of the current break frequency. The BFF is estimated by comparing current pipe failure rates with the low failure rates established for use in assessing Unavoidable Annual Real Losses (UARL)[22]. The UARL concept was a significant developed made by the IWA Water Loss Task Force to allow assessment of recoverable leakage by recognizing that a component of unavoidable leakage exists which can never be totally removed from a utilities distribution system.

The results of data from 112 systems from 10 countries were assessed with the trends shown in Figure 3 emerging.

Figure 3: Pressure - Break Frequency Relationship



[20] From an confidential source, information yet to be published.

[21] Bamezai and Lessick 2003: Is System Pressure Reduction a Valuable Water Conservation Tool? Preliminary Evidence From the Irvine Ranch Water District.

[22] Developed by Allan Lambert, 1999.

The average BFF from this international data set emerges as 1.4, meaning that a permanent reduction of X% in maximum pressure will, on average, reduce new break frequency by 1.4 x X% and the upper and lower limits are respectively 2.8 x X% and 0.7 x X%.

In summary, by assessing the current break frequency against the unavoidable break frequency the Break Frequency Factor (BFF) can be established. Once the BFF is known then the % reduction in break frequency can be forecast for a % reduction in pressure. A reduction in break frequency reduces leakage levels and can also make significant repair cost savings when starting from a higher BFF.