IMPLEMENTATION OF PRESSURE MANAGEMENT IN MUNICIPAL WATER SUPPLY SYSTEMS

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ABSTRACT

Pressure management is one of the most important Water Demand Management interventions that can be implemented by a water utility in its efforts to reduce leakage. Since leakage is driven by pressure, any efforts which result in the reduction of water pressure for even part of the day will reduce the leakage to some extent. Despite the obvious benefits that can be derived through proper pressure management, relatively few water utilities around the world are in fact implementing any form of pressure control.

If implemented correctly, pressure management can be successful in reducing leakage from existing and new burst pipes as well as reducing the hidden and often overlooked background leakage. In certain circumstances, pressure management can also result in a significant reduction in the "normal" consumption and will have the hidden benefit of extending the lifespan of the reticulation system. With so many positive aspects to pressure management it is therefore surprising to find that many water utilities around the world tend to shy away from such measures for a variety of reasons, most of which are based on popular misconceptions. Virtually every water supply system which is operating on a full 24-hour pressurised supply has some scope for pressure management whether or not it is a flat area or very hilly. The paper will provide additional information on the key issues to be considered when contemplating the implementation of pressure management. It will also explain the basic concepts of advanced pressure control where pressures are controlled using electronic or hydraulically operated modulating devices which provide greater flexibility and this also greater savings.

The paper will conclude with some details from several of the largest advanced pressure control installations implemented in the world. These installations are fully operational in South Africa and have been widely recognised as some of the most significant water demand management projects of their type in the world.

The paper discusses some of the key issues that must be considered when assessing the scope for pressure management from a practical viewpoint based on the experience gained through the implementation of over 200 installations. It addresses specific problems that were experienced in the implementation of the Khayelitsha installation in Cape Town as well as the Sebokeng installation in Gauteng, both of which supply water to over 500 000 residents through a single installation. The new Mitchell's Plain installation in Cape Town will also be discussed which supplies water to a similar sized community and was only commissioned towards the end of 2008. Between these three installations, savings of over 20 million kilolitres of water are achieved each year representing more than $6 million per annum.

INTRODUCTION

Many towns and cities around the world are facing a growing problem of providing sufficient water to support their growing demands. In many instances, this requires the construction of new and expensive infrastructure and in extreme cases it may be necessary to develop new water resource transfer schemes which can be prohibitively expensive and come with their own set of unique problems. In view of the increasing awareness of the environment and the need to manage the available resources in a more efficient manner, the global trend towards water conservation and water demand management is accelerating. Great progress in the field of water demand management has been made over the past decade and there are now many examples throughout the world where leakage and other forms of wastage have been significantly reduced through a range of water demand management interventions. Every system is different from each other and there is no single solution that will address the problems experienced by the particular water supplier.

The International Water Association (IWA) has taken the lead in creating a Water losses-Task Force which has been operating for almost 10 years to develop a pragmatic approach to reducing water leakage and other forms of wastage from municipal water supply systems. In this regard, the standard IWA water balance (**WRC, 2002**) was one of the most important and useful tools which forms the basis on which a comprehensive Water Demand Management strategy can be developed. The subsequent water demand management strategy will normally be tailored to each specific area and will often include a wide range of WDM interventions.

One of the most important WDM interventions that should be considered when developing a comprehensive WDM strategy for an area is pressure management. While it must be acknowledged, that pressure management is not the answer in every case, it is often one of the most cost effective measures to reduce leakage and wastage that can be considered. In many parts of South Africa, pressure management is by far the most important WDM intervention and is often the first WDM intervention to be implemented.

South Africa was one of the first countries in the world to adopt the principles of advanced pressure control as developed in the UK for the UK water industry back in the early 1990's. The techniques used in the UK were first presented in South Africa in 1993 and following a series of small pilot projects, the full scale Johannesburg Pressure Management Project was completed in 1995 by two different teams involving the design and commissioning of almost 100 advanced pressure control installations (**Mckenzie, Wegelin & Rhoner, 2000**). As with any new technology, there were teething problems and many lessons were learned, however, the benefits derived from the pressure management were significant and the project was recognised by SAICE for innovation and technical excellence.

Following the success of the Johannesburg project, one of the most ambitious pressure management projects undertaken anywhere in the world was designed and commissioned in 2001 in Khayelitsha for the City of Cape Town (**Mckenzie, 2002**). At the time, this was the largest installation of its type in the world and received two national prizes and one international prize for technical excellence. This installation was the forerunner to what is currently the largest installation of its type in the world which is located in Emfuleni Local Municipality at the supply point to the Sebokeng and Evaton areas. This project was commissioned in 2005 and also received recognition from various national and international organisations for its unique concept in which a performance based contract was implemented as part of a small scale public private partnership (**Wegelin and Mckenzie, 2005**).

The most recent large scale advanced pressure management installation was commissioned in Mitchel's Plain for the City of Cape Town in November 2008 and is now the 3rd large scale pressure management installation in South Africa. Each of these three installations controls the supply of water to approximately 500 000 residents from a single supply point (**Meyer, Wright & Engebrecht, 2009**). It is interesting to note, that South Africa is one of the few countries in the world where such installations are viable due to the nature of the water supply systems and the government policy to supply free basic water at relatively high service levels.

The remainder of this paper will discuss the concepts of pressure management and advanced pressure control and also provide some details and results from the three large installations mentioned above. It will conclude with a summary of the key factors leading to the successful implementation of a large pressure management installation and explain why South Africa is ideally positioned to implement pressure management throughout the country.

CONCEPTS OF PRESSURE MANAGEMENT

Water supply systems worldwide are generally designed to provide water to consumers at some agreed level of service which is often defined as a minimum level of pressure at the critical point which is the point of lowest pressure in the system. In addition, there may be certain fire-flow requirements which can over-ride the normal consumer requirements. The systems are designed to accommodate these pressure and flow requirements during the period of peak demand which would normally occur at some specific time of the day and during a particular month in the year. In other words, the systems are designed to provide the appropriate supply during a very short period in the year and for the remainder of the time the systems tend to operate at pressures significantly higher than required. Even within the same system, there will be areas of high pressure due to topography and/or distance from the supply point with the result that many parts of a supply area will operate at pressures significantly higher than required in order to ensure that there is sufficient pressure at the one critical point.

Managing water pressures in a supply area is not a simple issue and there are a great many items to consider. The common factor in every system is the fact that leakage is driven by pressure and if the pressure is increased, the leakage will also increase. Conversely, if the water pressure can be reduced, even for part of the day, the leakage will also decrease. No two systems react in the same manner to pressure and it is often very difficult to predict the reduction in leakage due to a decrease in pressure with confidence. Many theories have been postulated to explain the pressure-leakage relationships in a municipal water supply system and the most widely accepted theory is that of Fixed and Variable Area Discharges (FAVAD) which was first suggested by John May from the UK water industry in 1995 This theory is fully explained by May in his paper (**May, 1994**) and further details are provided in the PRESMAC User Manual (**WRC, 2001**).

In summary, the relationship between pressure and leakage will conform to a square-root relationship (N1 = 0.5) in cases where the size of the leakage path (i.e. hole) remains constant during the change in pressure. This is the typical situation when the leak is a small hole in an iron or steel pipe (i.e. a fixed area leak) in which case doubling pressure will result in approximately a 41% increase in leakage. In the case of leaks from plastic pipes or from cracks in asbestos cement pipes, the surface area of the leakage path does not remain constant when the pressure changes and such leaks will often open up to create a larger hole through which the water can leak. Such leaks are referred to as variable area leaks and if the pressure is doubled, the leakage will increase more than from a fixed area leak. In some cases, the leakage will increase by as much as 8 times the original level (N1 = 3).

In most systems, there tends to be a mixture of fixed area and variable area leaks and the split will depend on the proportion of steel/iron pipes to plastic/asbestos pipes. Many papers have been presented on this topic in which formulae are provided to predict the impact of changes in pressure on leakage. From the author's experience, it is often found that certain other factors play a more critical role in the pressure-leakage relationship. For example, it has been found in many parts of South Africa that the quality of workmanship when laying the pipes is one of the most important factors influencing the leakage. Two similar systems next to each other can have significantly different leakage characteristics simply because one system was laid properly with adequate site supervision while the other system was laid by a poorly qualified contractor with poor supervision. In such cases, there is no adequate theory to explain the different responses to changes in pressure.

In order to reduce leakage through pressure management it is necessary to reduce the water pressure without compromising the level of service with regard to the consumers and fire-fighting. As mentioned previously, most systems are designed to provide a certain minimum level of service in the system during the peak demand period as shown in **Figure 1**. In this example it is assumed that a minimum pressure of 20m is required.

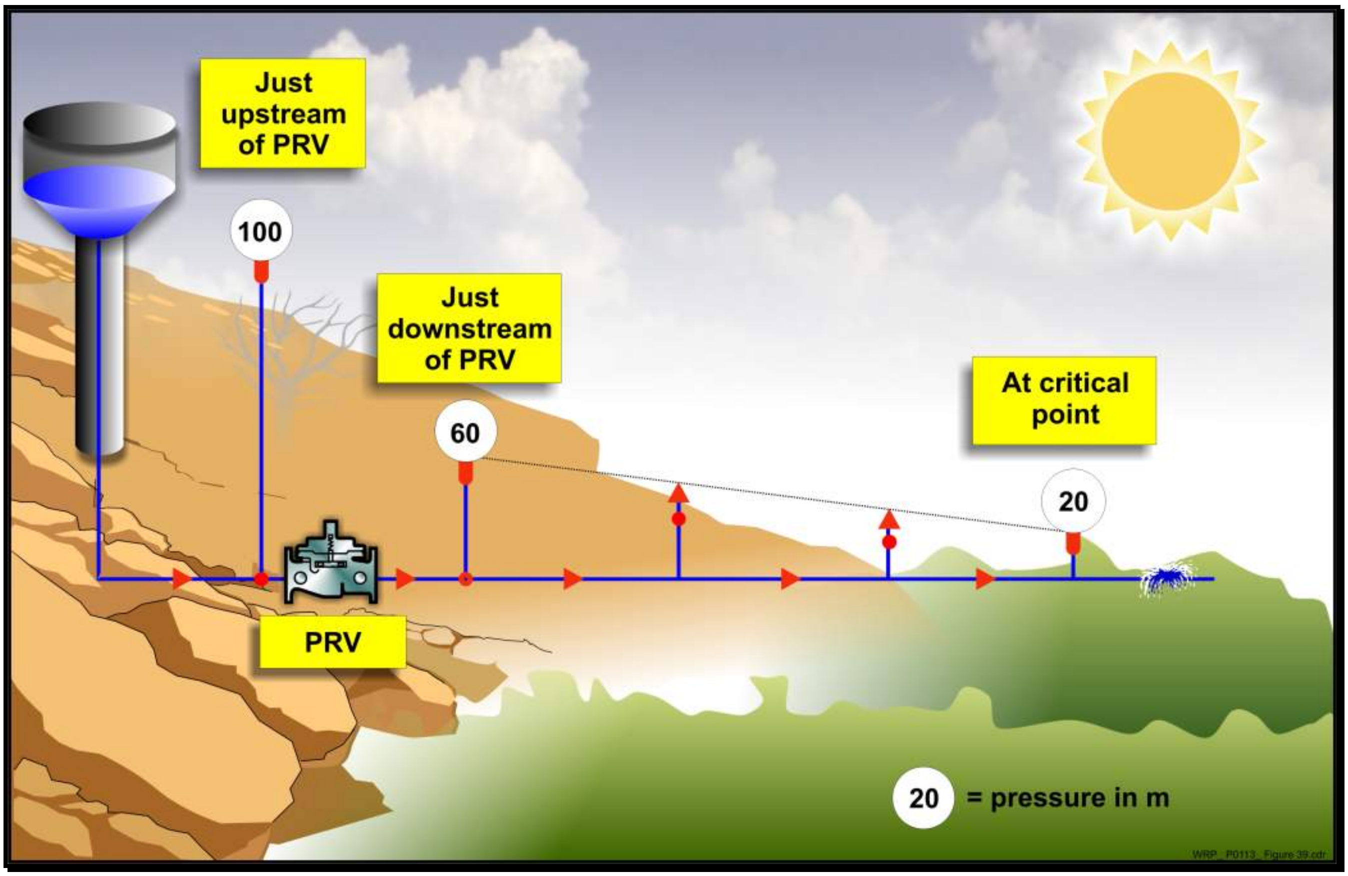

Figure 1: Typical pressure during peak demand periods

During the off-peak periods, which tend to much greater than the peak periods, the system operates at a water pressure which is significantly higher than necessary as shown in **Figure** 2. In effect, there are long periods when there is significant scope for pressure reduction and this is the basis on which the pressure management interventions are designed.

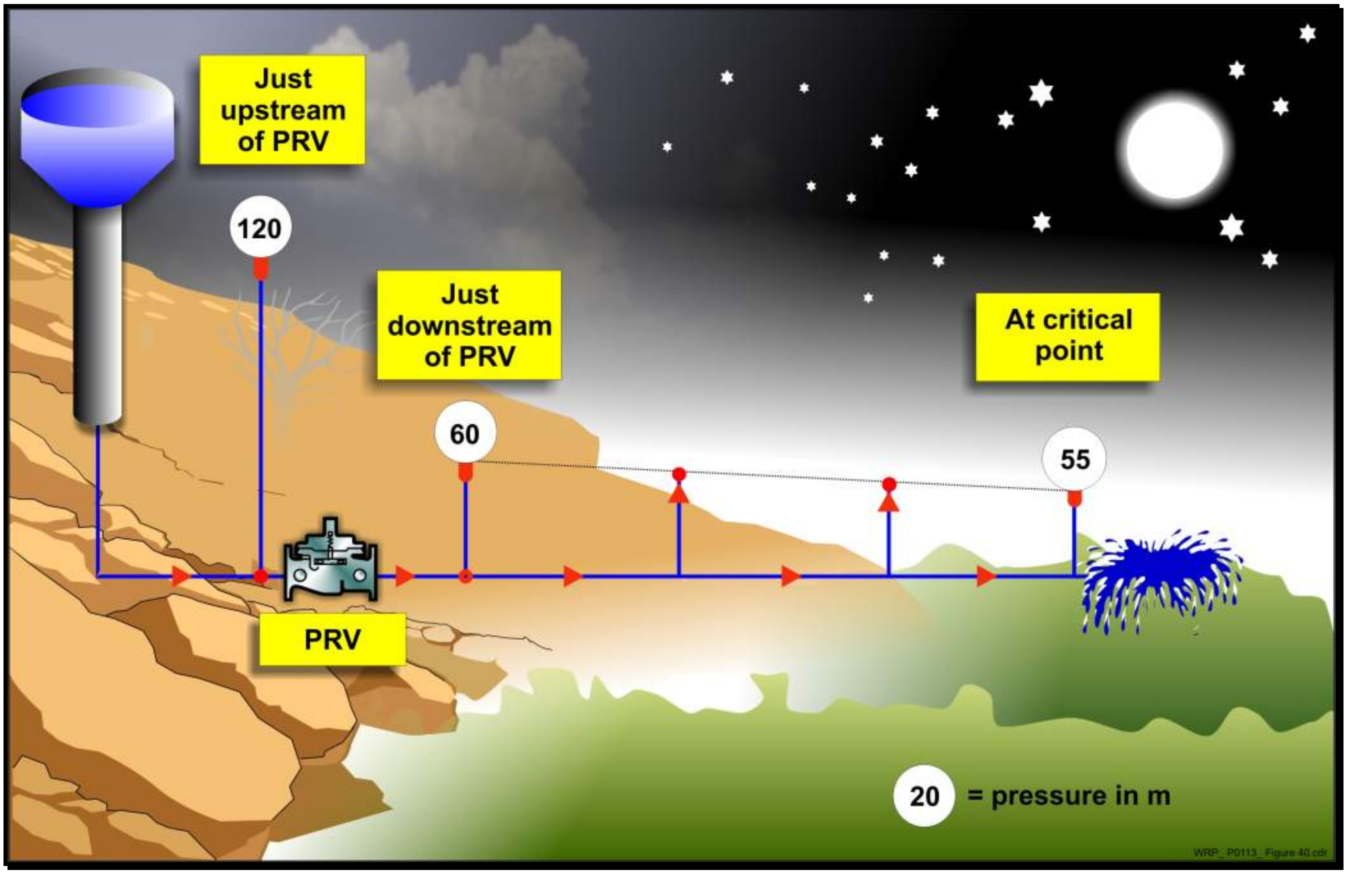

Figure 2: Typical pressure during off-peak periods

Reducing the water pressure in a system can be achieved in a number of ways each of which has advantages and disadvantages. The following techniques are discussed:

- Fixed outlet pressure control
- Time-modulated pressure control
- Flow modulated pressure control

Fixed outlet pressure control involves the use of a device, normally a pressure reducing valve (PRV) which is used to control the maximum pressure entering a zone as can be seen in **Figure 3**. This is possibly the simplest and most straightforward form of pressure management as it involves the use of a PRV with no additional equipment. The advantages of this form of pressure control are:

- It is relatively simple to install as it requires only a PRV
- Cost is relatively low as it involves no electronic equipment;
- Maintenance and operation is relatively simple

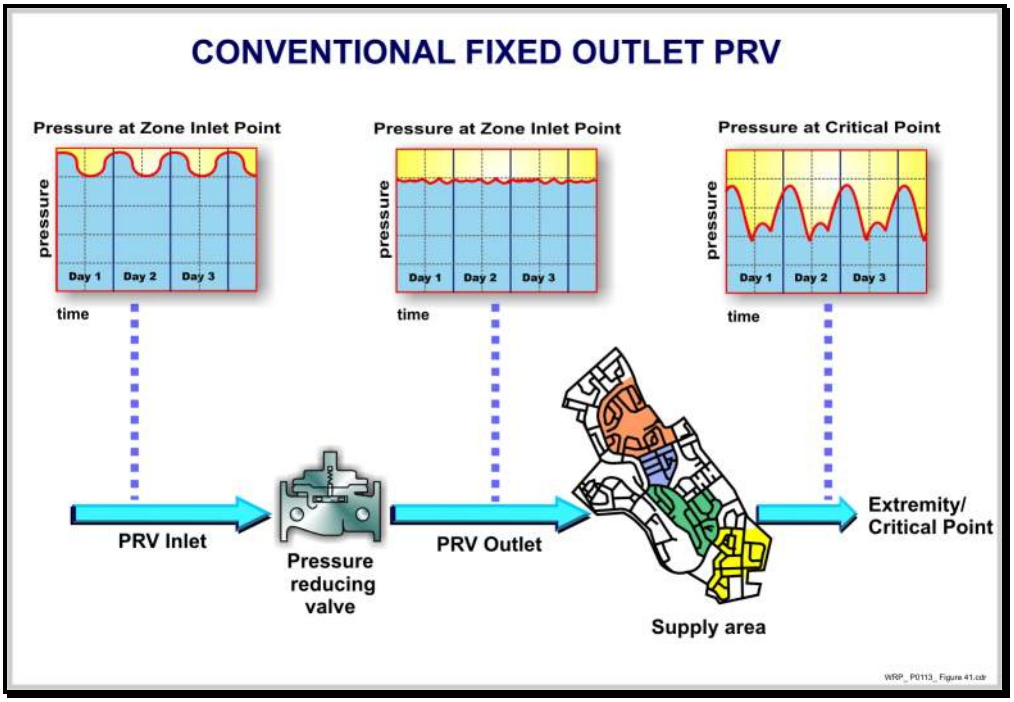

Figure 3: Fixed outlet pressure control

The only disadvantage is that the system does not have the flexibility to adjust the water pressures at different times of the day with the result that the maximum possible savings cannot be achieved. In many instances, fixed outlet pressure control is the preferred option due to the capacity of the maintenance teams who may not be able to operate and maintain the additional equipment required when using the time-modulated and flow-modulated options.

The time-modulated pressure management option is shown in **Figure 4** and is effectively the same as the fixed-outlet system with an additional device which can provide a further reduction in pressure during off-peak periods. This form of pressure control is useful in areas where water pressures build up during the off-peak periods – typically during the night when most of the consumers are asleep. The main advantages of this option are:

- The controller provides greater flexibility by allowing pressures to be reduced at specific times of the day, resulting in greater savings.
- The electronic controller is cheaper than the more expensive flow-modulated option;
- The controller is relatively easy to set up and operate.
- The installation does not require a flow meter as the controller connects directly to the pilot on the PRV.

The main disadvantage of time-modulated control is that it does not react to the demand for water and this can be a problem if a fire breaks out requiring full pressure for fire-fighting. This problem can be overcome to some extent through the installation of a flow meter. In addition, the time-modulated option is more expensive than the fixed outlet option and does require a higher level of expertise to operate and maintain the installations.

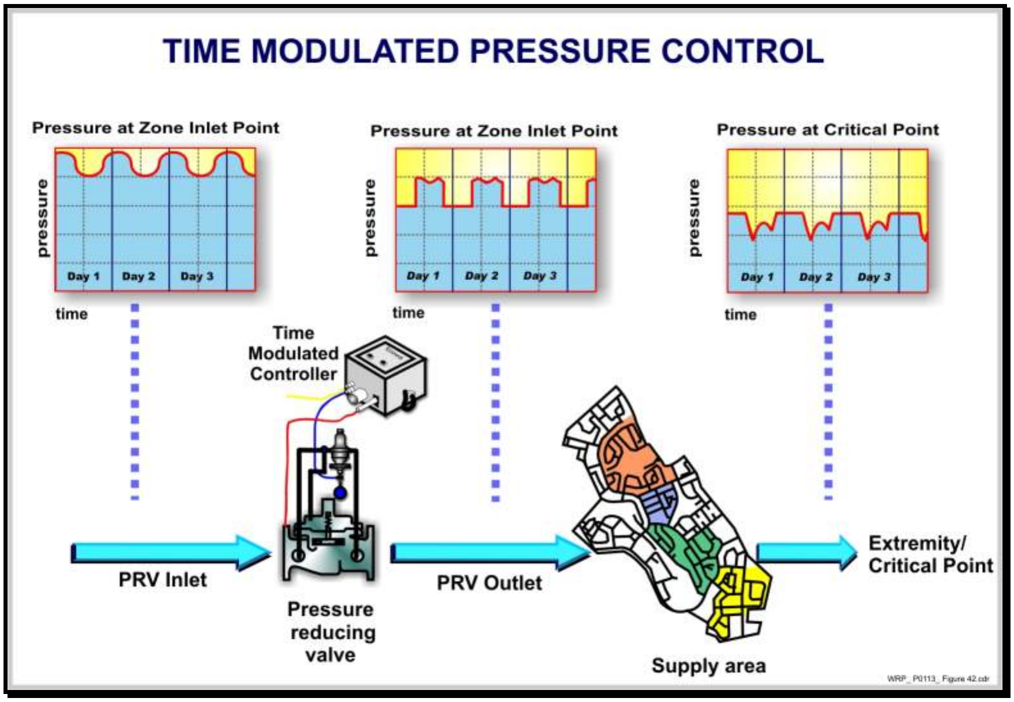

Figure 4: Time-modulated pressure control

Flow modulated pressure control as shown in **Figure 5** provides even greater control and flexibility than the time-modulated option. It will normally provide greater savings than either of the two previously mentioned options but this greater flexibility (and savings) comes at a price. The electronic controller is more expensive and it requires a properly sized meter in addition to the PRV. It may not always be cost effective to use the flow modulated option and careful consideration should be given to the specific application before selecting flow-modulated control. One key advantage is that the flow modulated option will not hamper the water supply in the case of a fire but the additional savings achieved my be offset against the extra cost of the controller and need for a meter.

In most cases, the approach depicted in **Figure 5** is as sophisticated as most water utilities will consider. In many instances, the use of flow modulated control is beyond the human resource skills base of the water utility and as a result time-modulated control is the preferred option. In recent years, however, several “closed-loop” systems have been implemented in various parts of the world where a pressure sensor at the critical point is used to provide live data to the pressure controller at the inlet to the zone. This form of pressure control as shown in **Figure 6** provides the ultimate level of control and therefore also the maximum savings that can be achieved. It is, however, the most complicated form of pressure control and there is greater opportunity for equipment to fail. Each pressure management system has its advantages and disadvantages. The key issue is to select the most appropriate form of pressure control for a specific application which involves taking the available budget and technical capabilities of the client into account.

It should be noted that there are numerous other forms of pressure control which can be considered when trying to reduce losses from a water distribution system. Several hydraulic controllers are now also available in addition to a number of devices based on a simple orifice plate. No-matter what approach is selected, if the water pressure in an area can be reduced for even a short period, there will be a reduction in leakage.

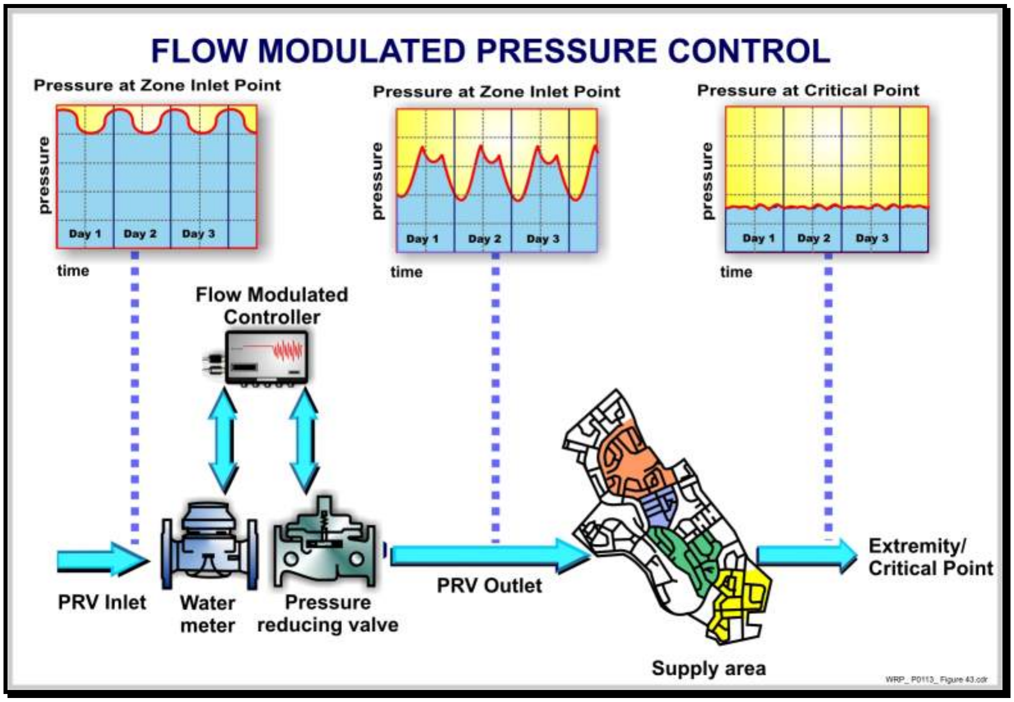

Figure 5: Flow modulated pressure control

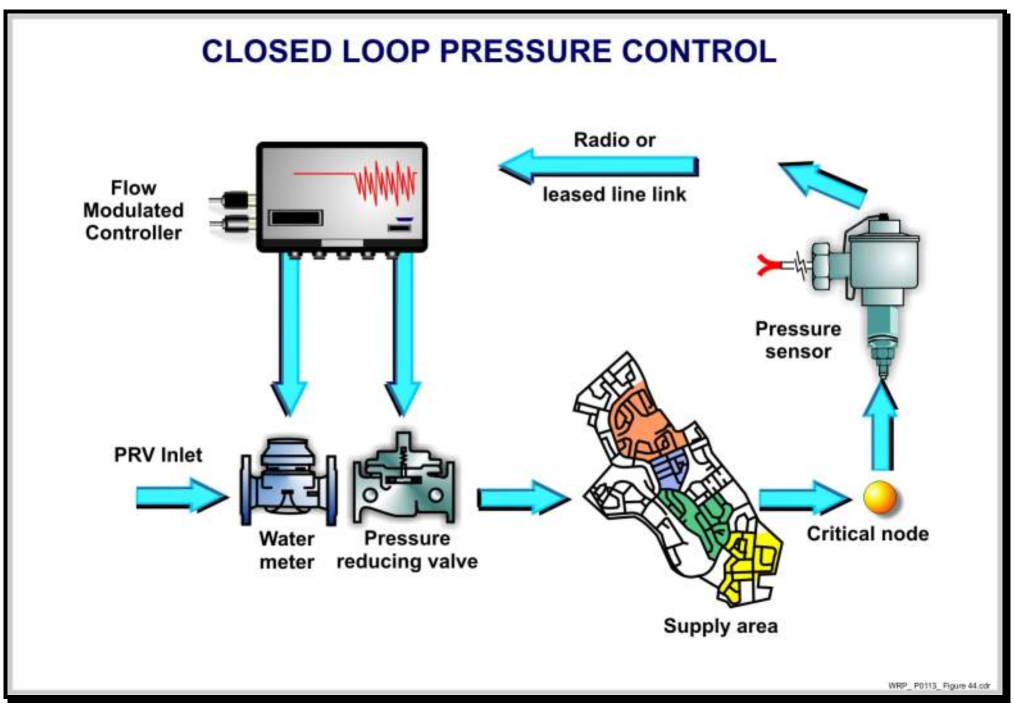

Figure 6: Closed loop pressure control

CASE STUDIES

There are several hundred advanced pressure control installations in South Africa including three of the largest installations of their type in the world. While many of the smaller installations are of significance and of interest for a variety of reasons, only the three largest installations are discussed in this paper namely, Khayelitsha, Sebokeng and most recently Mitchells Plain. Each of these installations is noteworthy for various reasons as discussed below.

Khayelitsha : City of Cape Town - 2001

Khayelitsha is one of the largest townships in South Africa and is located approximately 20 km from Cape Town on the Cape Flats which is a large flat sandy area at or near sea level. There are approximately 43 000 serviced sites with both internal water supply and water borne sewage while there are a further 27 000 low-cost housing units which are supplied from communal standpipes supporting a population of approximately 450 000.

At the beginning of 2000 the water supplied to Khayelitsha was measured to be almost 22 million m^3/a. The level of leakage was estimated from the night-time water use to be almost three-quarters of the water supplied to the area. The Minimum Night Flow (MNF) was measured to be in excess of 1 600 m^3/hr which is sufficient to fill an Olympic sized swimming pool every hour.

The main source of the leakage was identified as the household plumbing fittings which have been badly damaged through constant exposure to a relatively high pressure of 80m. Such leakage resulted in very high water consumption in most properties and high levels of non-payment since the customers could not afford to pay for new taps and toilet fittings let alone the high water bills.

The Khayelitsha Pressure Management Project was commissioned in 2001 to improve the level of service to the Khayelitsha community by reducing the excessive water pressure and pressure fluctuations in the reticulation system. The layout of the installation is provided in **Figure 7**.

The average daily flow was reduced from 2 500 m^3/hr to 1500 m^3/hr representing an annual saving of 9 million m3/hr or approximately 40% of the original water use. The Minimum Night Flow was reduced from 1 600 m^3/hr to 750 m^3/hr. Local labour was used throughout the project and the community support was a key factor in the successful implementation of the project. A summary of the actual savings achieved from the first two years of operation is provided in **Table 1** (**Mckenzie, Mostert & Wegelin, 2003**). It should be noted that the latest estimates of savings achieved from the installation made by the City of Cape Town suggest savings of 9 million m^3/a with a financial saving of R54 million per year (± $6 million/a) (**Meyer, Wright and Englebrecht , 2009**).

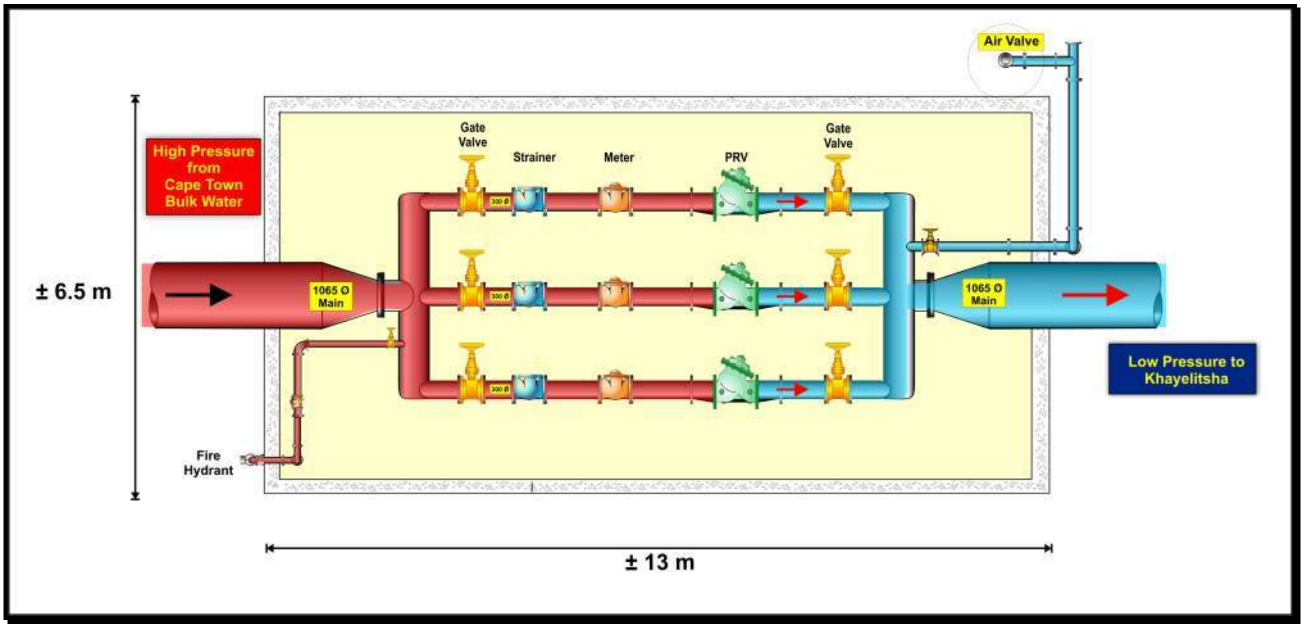

Figure 7: Schematic layout of Khayelitsha installation

The completed installation is shown in **Figure 8** and **Figure 9**.

Table 1: Summary of Khayelitsha savings for initial 2 year period

Description	Basis of calculation	Volume saved	Value of saving (R million)
Direct water savings in 2002	Based on R3.09/ m^3	9 million m^3	27.8
Direct water saving in 2003	Based on R3.49/ m^3	9 million m^3	31.4
Delay to infrastructure – 2 years	7% of R35 million/yr		4.9
Maintenance and replacement	R250 000 per year		-0.5
Total saving over 2 year period			**63.6**

Figure 8: Khayelitsha pressure management installation

Figure 9: External view of the Khayelitsha pressure management installation

Sebokeng : Emfuleni Local Municipality – 2005

Emfuleni Local Municipality is located to the south of Johannesburg in the industrial heartland of South Africa. The municipality supplies water to approximately 1.2 million residents of which 450 000 are located in the Sebokeng and Evaton areas. The areas are predominantly low-income residential areas with approximately 70 000 household connections, each of which is supplied with an individual water supply as well as water borne sewage. The combination of low income coupled with high unemployment has resulted in a general deterioration of the internal plumbing fittings over a period of many years causing high levels of leakage which is characterised by a minimum night flow in the order of 2 800 m^3/hr. This is one of the highest minimum night flows recorded anywhere in the world and represents almost two Olympic sized swimming pools of water every hour during a period when demand for water should be minimal. It was estimated that the wastage in the area before the project was commissioned was in the order of 80% of the water supplied to the area which in turn represented an annual water bill of approximately R120 million per year (±$12 million).

In 2004, the municipality commissioned one of the largest advanced pressure management installations in the world as the first phase of a long term strategy to reduce wastage in the area. The project involved no financial input from the Municipality and even the initial capital costs were borne in total by the Project Team. The project was, effectively, a small scale Public Private Partnership involving a simple risk-reward model details of which are provided in **Figure 10** (**Mckenzie and Wegelin, 2005**).

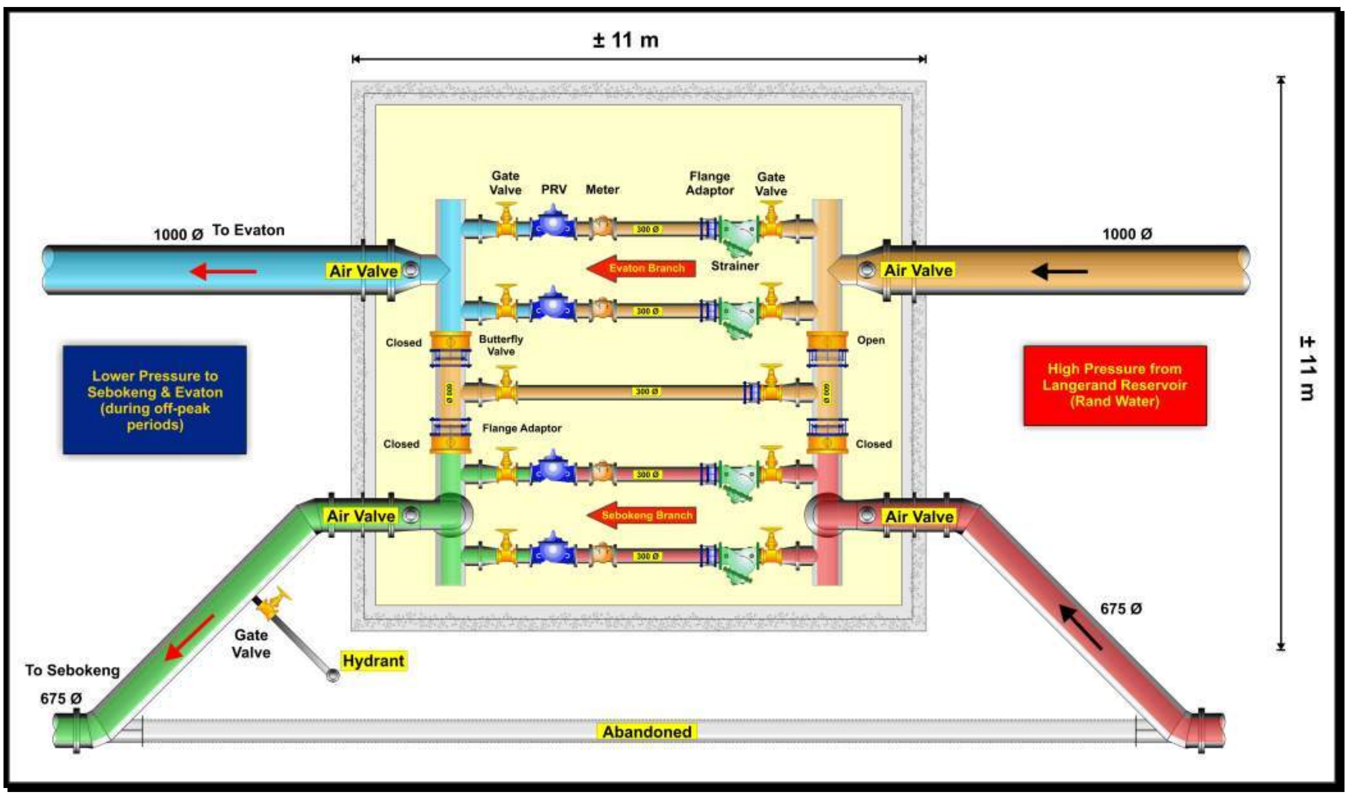

Figure 10: Schematic layout of Sebokeng installation

The savings achieved in the first 30 months of operation of the installation exceeded all expectations of both the Project Team as well as the Municipality and are the most obvious benefits to accrue from the project. After operating and managing the installation for two years, several other benefits also became apparent which were not initially anticipated. In particular the following benefits have been achieved:

- Defer upgrading of infrastructure
- Identification of bottlenecks in the system and problem infrastructure;
- Identification of bulk meter errors;
- Catalyst for funding;
- Improved Municipality Status
- Creation of National WDM fund;
- Catalyst for other WDM interventions;
- Sustainability of Savings.

The project represents a significant advancement in Public-Private Partnerships (PPP's) and clearly demonstrates that small scale Public Private Partnerships can be viable despite the general view that this type of project is confined to large scale initiatives due to the effort and expense in developing the PPP type of contract. While the Sebokeng and Evaton Public Private Partnership is clearly one of the most successful small scale PPP's to be completed in South Africa, the real benefits of the project are only now materialising four years after the project was commissioned. Both the Project Team and the Municipality are very happy with the outcome of the project and are continuing to work together to build on the initial success. While the financial savings generated exceed all initial expectations, the hidden and often less tangible benefits greatly outweigh the obvious and tangible benefits.

The actual savings achieved are summarised in **Table 2** and also depicted graphically in **Figure 11**. As can be seen from **Figure 11**, the water supplied to the area at the start of 2008 is almost the same as it was at the start of 2001 which clearly highlights the true level of savings that have been achieved.

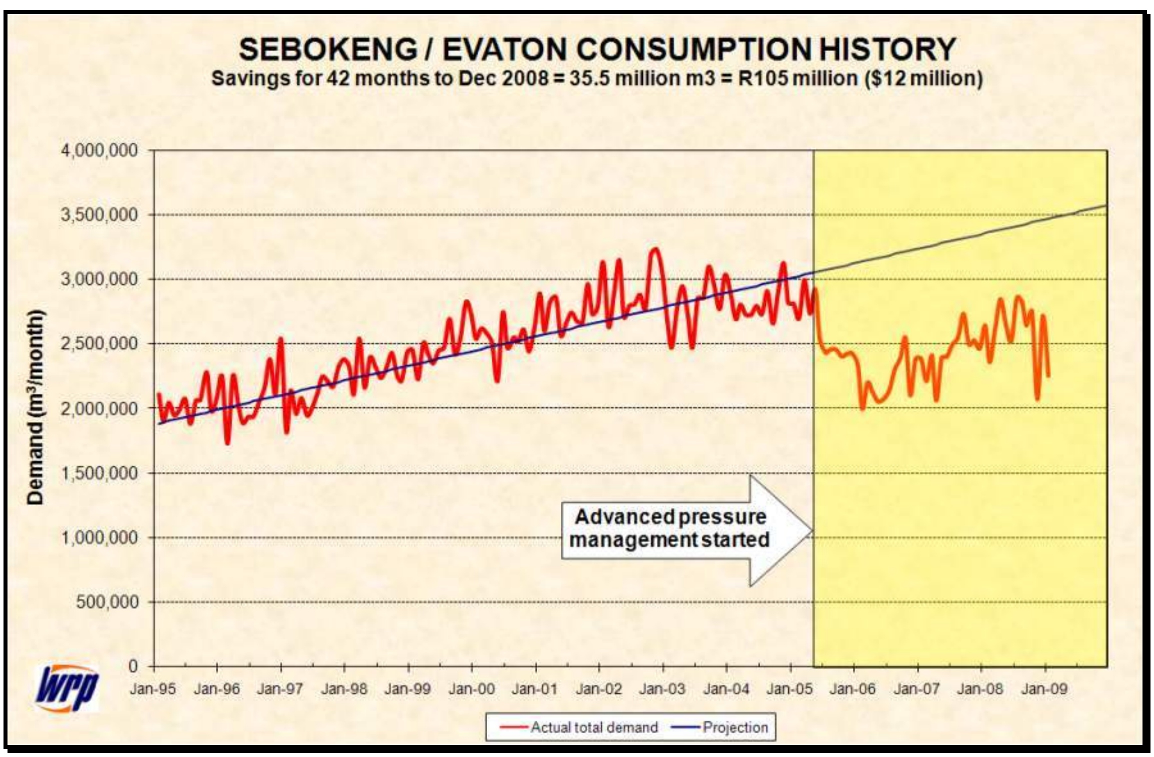

Figure 11: Historical water consumption in Sebokeng and Evaton areas for a 13 year period

Table 2: Summary of Sebokeng savings for first 42 months of operation

Period	Water Consumption (Kl)			Savings	
	Expected	Actual	Saving	Rands	US$
Months 1 to 6	18 721 000	14 614 000	4 107 000	11 499 600	1 437 450
Months 7 to 12	18 751 000	12 785 930	5 965 070	16 702 196	2 024 509
Months 13 to 18	19 403 000	13 886 451	5 516 549	16 218 654	1 908 077
Months 19 to 24	19 423 000	13 877 370	5 545 630	16 304 152	1 863 332
Months 25 to 30	20 086 000	15 269 040	4 816 960	14 788 067	1 643 119
Months 31 to 36	20 206 000	15 633 153	4 572 847	14 038 640	1 517 691
Months 37 to 42	20 827 000	15 870 850	4 956 150	16 107 488	1 695 525
Totals	**137 417 000**	**101 936 794**	**35 480 206**	**105 658 797**	**12 089 702**

The completed Sebokeng/Evaton pressure management installation is shown in Figure 12 and Figure 13.

Figure 12: Sebokeng/Evaton pressure management installation

Figure 13: External view of the Sebokeng pressure management installation

MITCHELLS PLAIN: CITY OF CAPE TOWN – November 2008

In order to meet the growing water demands within the City of Cape Town's supply area, several large and expensive water transfer schemes have been commissioned in addition to the ongoing water demand management interventions. One of the most significant water loss reduction activities involves the use of advanced pressure management. Since the City of Cape Town receives its most of its water via the Blackheath Water Purification Plant which stores the bulk water in a large reservoir at an elevation of approximately 110m above sea level, many low lying areas are supplied at very high pressures leading to high levels of leakage. This is particularly evident in the low lying and relatively flat sandy areas referred to as the Cape Flats. Such areas are therefore ideally suited to pressure management which has in turn resulted in the city embarking on several large scale pressure management projects.

The City of Cape Town was the first city in South Africa and one of the first major cities in the world to successfully commission a large scale pressure management project specifically to reduce leakage during off-peak periods. The Khayelitsha installation was the first of three such installations to be commissioned in South Africa and was completed in 2001 amid great publicity and press coverage. Since then, the City of Cape Town has implemented pressure management in a number of other areas which were relatively small in comparison with Khayelitsha which supports a population of almost 500 000 residents. In 2008, however, the city decided to commission its 2nd major pressure management installation in the Mitchell's Plain area which supports a similar population to Khayelitsha. This project was commissioned in October 2008 and details of the installation are provided in **Figure 14** and **Figure 15**. The projected water savings based on the initial flow logging results indicate that it will save approximately 2.4 million m^3/a with a value of R 14 million ($1.5 million) resulting in a pay-back of less than 6 months.

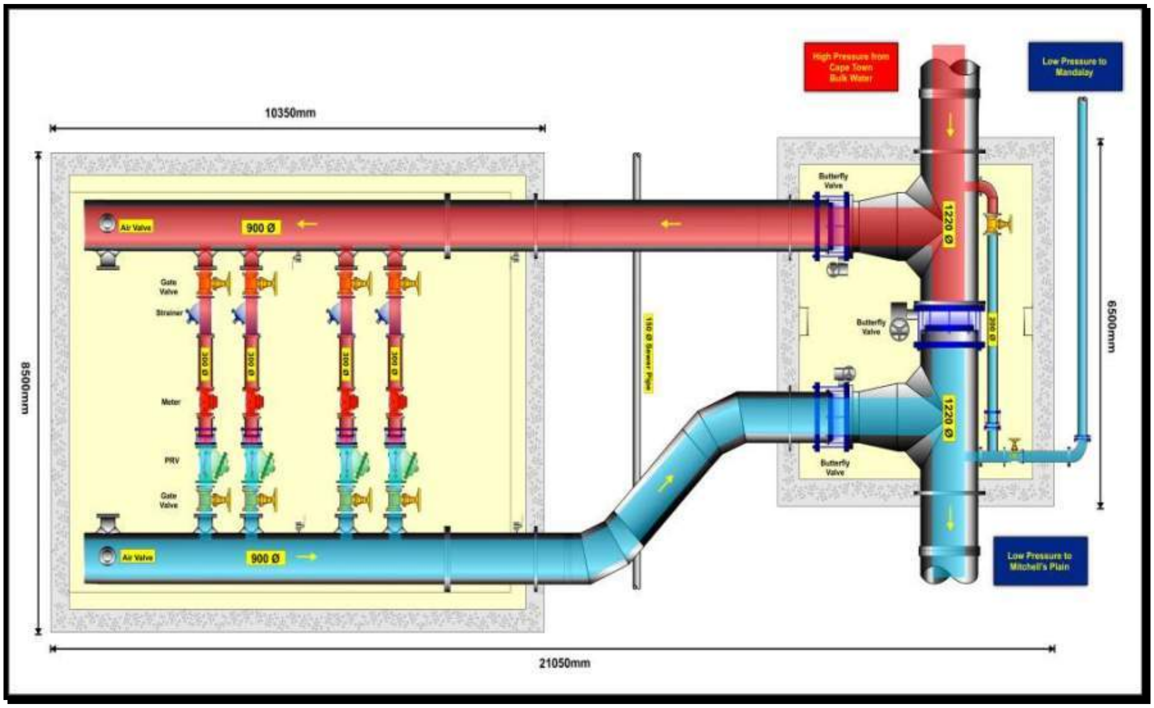

Figure 14: Schematic layout of the Mitchells Plain installation

Figure 15: Mitchells Plain pressure management installation

In order to promote the installation and emphasise the importance of water demand management in the community, the installation was painted by local artists in such a manner that it sends a strong message to all passers=by as can be seen in
Figure 16.

Figure 16: External view of the Mitchells Plain installation

CONCLUSIONS

Based on the results from the three case studies discussed in this paper, it is clear that pressure management is highly effective in many parts of South Africa and that it can be implemented successfully on a large scale in certain areas. While it must always be remembered that pressure management is normally only the first phase of a larger water demand management strategy, it can often provide very significant savings in a short period of time. Pressure management also has many secondary benefits that are often overlooked including extending the useful life of the water reticulation system. Such a benefit can often far outweigh the initial benefits as calculated from the water savings but will only become apparent many years down the line.

South Africa was one of the first countries to recognise the benefits that can be derived from advanced pressure control and currently lays claim to three of the largest advanced pressure control installations in the world. The Khayelitsha and Sebokeng installations have received considerable recognition from various water utilities and funding agencies throughout the world and have often been used to highlight "world best practice" in the field of water conservation in action.

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REFERENCES

MAY, J. 1994. ***Pressure Dependent Leakage***. World Water and Environmental Engineering, October 1994.

McKenzie, R., Wegelin, W. and Rohner, K. , 2000 ***"Leakage Reduction Through Pressure Management in the Greater Johannesburg Area"***. American Water Works Association Annual conference, Denver, Colorado. June 11 to 15, 2000.

McKenzie, R., 2002 "**Khayelitsha: Leakage Reduction through Advanced Pressure Control**. Journal of the Institution of Municipal Engineering of South Africa, Volume 27, No 8, pp43 to 47 August 2002.

McKenzie, R., Mostert, H and Wegelin, W., 2003 **Leakage Reduction through Pressure Management in Khayelitsha**, ***Western Cape: South Africa***. Paper presented at the Australian Water Association Annual Conference, Perth, 7-10 April, 2003.

Meyer, N, Wright, D, Engelbrecht, M (2009), ***Large scale pressure management implementation in the City of Cape Town*** , IWA Water Loss Conference (04/09).

Water Research Commission.,2002. ***"Development of a simple and pragmatic approach to benchmark real losses in potable was distribution systems in South Africa": BENCHLEAK***. Report TT159/01 published by the South African Water Research Commission, January 2002. ISBN No. 1 86845 773 7

Water Research Commission., 2001 "***Development of a pragmatic approach to evaluate the potential savings from pressure management in potable was distributions in South Africa": PRESMAC***. Report TT152/01 published by the South African Water Research Commission, July 2001. ISBN No. 1 86845 722 2

Wegelin W, & Mckenzie, RS.,2005 ***Sebokeng/Evaton Pressure Leakage Reduction: Public Private Partnership*****.** Proceedings from the International Water Association Specialist Conference: Leakage 2005, Halifax, Nova Scotia, Canada. pp 382-391. 12 - 14 September 2005.