

PRESSURE MANAGEMENT IN ADELAIDE METROPOLITAN NETWORK 
- FEASIBILITY STUDY -

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ABSTRACT

A feasibility study was undertaken to identify opportunities to reduce the frequency of pipe bursts through pressure management of the Adelaide Metropolitan Drinking Water Network. Following a detailed analysis of the current network, hydraulic modelling and undertaking field verification, three new modulated pressure zones were proposed within the network, covering 19% of the network length and 28% of the bursts history. The expected payback for the whole project is under 10 years if implemented.

INTRODUCTION

The Adelaide Metropolitan Drinking Water Network (Adelaide Metro) in South Australia is comprised of approximately 9,000km of pipeline which covers an area stretching 20km west to east from the coast to the foothills, and 90km south to north, from Myponga to Gawler. The network is split into more than 40 hydraulically independent pressure zones (EL) served by 120 tanks and seven Water Treatment Plants (WTPs).

The Adelaide Metro area has a burst frequency index of 21 bursts/100km. This burst rate has an associated repair cost for SA Water (SAW), and a potential impact on customers (water supply interruptions, traffic disruptions, potential damage to properties, etc).

Adelaide Metro is also characterised by a high average pressure, reaching more than 100m in some areas (SAW guidelines define an acceptable minimum pressure of 20m). As increases in pressure are directly correlated to increases in burst rate, pressure reduction/modulation using Pressure Reducing Valves (PRVs) is a well-known methodology applied worldwide by many water utilities to decrease the burst rate and associated impacts in the network.

In this context, a feasibility study on pressure management for the Adelaide Metro network was undertaken over a one year period and the associated process and outcomes are described in this paper.

METHODOLOGY / PROCESS

The technical side of the feasibility study on pressure management was conducted in three main steps: a desktop assessment of the current Adelaide Metro network, the boundary design of proposed new pressure zones and the definition of the target pressure within these zones.

Desktop assessment of Adelaide Metropolitan Network

For this desktop assessment, hydraulically and operationally consistent “macro sectors” were defined based on the current pressure zones and operational knowledge. An extensive assessment was then conducted through a Multi Criteria Analysis (MCA) to identify the sectors that would present the best potential for pressure management. Data analysed and compared for each sector included:
- GIS data: pipework length and diameter (DN), pipework age and material, type of soil, historical burst database for mains and service connections;
- Customer service data: consumption volumes, type of consumption, number of large customers;
- Hydraulic model data: daily and seasonal pressure variation, current maximum pressure, planned future developments; and
- Operational knowledge: low pressure/high pressure complaints areas, frequent burst areas, local specificities of the network

The MCA highlighted three sectors (namely the EL76, EL103 and EL170) which were identified as having a high burst rate, both on mains and connections, and a high average pressure, hence presenting the highest potential for pressure management implementation. The remainder of the study was therefore aimed at designing new sub-pressure zones (at lower pressure) within these three existing zones.

Boundary design of the new pressure zones Guidelines of Adelaide network today

The design of any new pressure zones will need to follow the SAW planning guidelines (SA Water Infrastructure Division, 1992) which include: Normal minimum operating pressure in the system of 20m, minimum flow rate of 0.45L/s, and first customers
within a pressure zone located at least 30m below the entry point (for instance a tank or a PRV).

Draft of the new zones
Within each of the three zones identified by the MCA, new sub-pressure zones were drafted on network maps following the steps below:
- Hydraulic assessment of the existing pressure zones (EL): entry points, exit points, network configuration, current operation, pressure distribution, etc.
- Selection of a new EL line with regards to contours, pipework and current average pressure, amongst others.
- Identification of the transmission mains which shall supply the new pressure zones from the existing tanks and on which PRVs shall be installed.
- Creation of the largest possible new pressure zones, respecting the design guidelines, with the aim of:
  - Minimising network changes, including the requirement for new infrastructure or for the upgrade of existing infrastructure;
  - Securing supply for the remaining and new pressure zones, by maintaining as much network balance as possible, and keeping network redundancy on important mains where possible;
  - Ensuring no degradation of water quality (minimising dead ends).
- Integration of areas currently experiencing low pressure (if any) within the vicinity of the low elevation boundary of the new pressure zones.

This process resulted in a high level draft of three new pressure modulated (M) zones:
- EL66M within the current EL76, to be supplied by two PRVs (one already existing, currently delivering to a flat pressure setpoint, but with the possibility of modulation setup),
- EL75M within the current EL103, to be supplied by three PRVs,
- EL140M within the current EL170, to be supplied by seven PRVs. This new zone would incorporate suburbs of the EL103 currently experiencing low pressure problems.

These three new zones combined would cover approximately 19% of the Adelaide Metro network length, 18% of the water meters and target 28% of the bursts on water mains.

Integration of the draft zones in the hydraulic model
These new boundaries were then integrated in the full Adelaide Metro hydraulic model and iterated multiple times to:
- Reach a satisfactory hydraulic performance of the whole system, meeting SAW guidelines, both in the new and in the remaining zones;
- Optimise the number of PRVs supplying each zone;
- Assess and list the required network changes (on top of the PRVs):
  - New cross connections (CC) required to improve the hydraulic connectivity and/or to avoid dead ends;
  - New Lock Stop Valves (LSVs) required to close the new boundaries, whether by reusing existing valves or by installing new ones; and
  - Existing LSVs to be reopened where customers with current low pressure in a lower EL will be pushed to the new higher modulated zone.

The modelling was conducted under peak summer demand and assuming the PRVs are set to a flat HGL setpoint (of respectively 66m, 75m and 140m), allowing a worst case boundary design with no modulation to higher pressure.

Field checks
In parallel with the modification of the boundaries in the hydraulic model, various field checks were undertaken to validate or adjust the proposed design:
- Site check of the high boundaries: the high boundaries of each proposed zone were driven along to identify any high buildings or customers with special needs that would not necessarily be captured in the hydraulic model and that may need to be kept out of the new modulated zone, or that may become a critical point of the PRV control system.
- Meetings with network technicians: discussions were organised to gain knowledge of the network that would be impacting the project, for example, pipework known to be rusty or problematic, known areas of low pressure, known customers with special needs, etc.
- Site check of the proposed 11 PRV locations: The new PRVs were created in the model at the most hydraulically desirable location. The GIS was then scrutinised to find a realistic and ideal location within a suitable hydraulic perimeter (not in the middle of the road, parklands, carpark, existing SAW land, etc). Site checks were finally undertaken to validate these proposed locations or to find another one within the vicinity.
- Pressure logging: loggers were installed at critical points of the network (end of the network, known critical areas, known unreliable area of the hydraulic model, proposed PRV locations, etc.) to validate the model results under the current configuration and to highlight any network specificities that the model would not necessarily capture.
- Site checks of existing assets impacted by the project: some existing assets (mostly PRVs) within the new modulated boundaries would have their operation impacted by a decrease in pressure on their suction side. This infrastructure was visited with the operators to
understand the current controls, assess the impact of the project and estimate the cost associated with an upgrade where required.

**Summary of the boundary design**

Table 1 summarises the characteristics of each of the proposed new zones. Percentages in brackets indicate the contribution of each zone when compared to the whole Adelaide Metro network.

**Table 1: Output of boundary design**

<table>
<thead>
<tr>
<th>Zone</th>
<th>66M</th>
<th>75M</th>
<th>140M</th>
</tr>
</thead>
<tbody>
<tr>
<td>Network Length (km)</td>
<td>540 (6%)</td>
<td>420 (5%)</td>
<td>730 (8%)</td>
</tr>
<tr>
<td># of meters</td>
<td>29,000 (6%)</td>
<td>27,000 (6%)</td>
<td>41,500 (9%)</td>
</tr>
<tr>
<td>Consumption (ML/y)</td>
<td>6,900 (6%)</td>
<td>7,100 (6%)</td>
<td>10,300 (9%)</td>
</tr>
<tr>
<td>Current average pressure (m)</td>
<td>59</td>
<td>69</td>
<td>82</td>
</tr>
<tr>
<td># of bursts on watermains (#/year)</td>
<td>39 (2%)</td>
<td>125 (8%)</td>
<td>290 (18%)</td>
</tr>
<tr>
<td># of proposed PRVs</td>
<td>2</td>
<td>3</td>
<td>7</td>
</tr>
<tr>
<td># of proposed CCs</td>
<td>0</td>
<td>33</td>
<td>28</td>
</tr>
<tr>
<td># of proposed LSVs</td>
<td>0</td>
<td>106</td>
<td>154</td>
</tr>
</tbody>
</table>

Figure 1 gives an overview of the new zones in the context of the existing network.

**Figure 1: Modulated zones overview**

**Target pressure and operating mode definition**

**Target pressure and proposed pressure reduction**

The target pressure is the pressure that will be delivered at the critical points of the network. Defining the target pressure is required to calculate what the pressure reduction over the zone will be (number to be used in the calculation of savings) and what the PRV setting should look like (which will impact on the choice of equipment). The critical points can be the highest customers, the furthest points from the system inlet (or points poorly supplied), or an industrial customer with a specific pattern of consumption. Critical points were identified for each new zone during the field checks described previously, in known industrial areas or as high points along the high boundary. All other customers, whether they are at lower elevation or better supplied, will have a higher pressure than the target pressure.

The target pressure for residential customers was calculated considering a worst case of a four floor building along the high boundary. For industrial customers, there cannot be any rule since it will depend on each industrial process. For the purpose of this feasibility study, and in order to have a conservative approach, it was decided to add another 20m to the residential target pressure to cater for industrial needs. The target pressure is defined in Table 2.

**Table 2: Customers Comfort Pressure**

<table>
<thead>
<tr>
<th>Time of the day</th>
<th>Peak</th>
<th>Off Peak</th>
<th>Night</th>
</tr>
</thead>
<tbody>
<tr>
<td>5:00–8:00</td>
<td>26m</td>
<td>22m</td>
<td>20m</td>
</tr>
<tr>
<td>11:00–13:00</td>
<td>46m</td>
<td>42m</td>
<td>40m</td>
</tr>
<tr>
<td>17:00–21:00</td>
<td>20m</td>
<td>20m</td>
<td>20m</td>
</tr>
</tbody>
</table>

For each zone and for each critical point, the current pressure (peak summer within the new boundaries) was compared to the target pressure to calculate the maximum possible pressure reduction at each modeling time step. A daily average was then calculated and converted into a percentage at the Average Zone Point (AZP). The AZPs are considered to be representative of the average pressure of the zone and were identified in each zone using a demand weighted average pressure from the hydraulic model. This percentage was used to calculate the expected savings.

Results are presented in Table 3.

**Table 3: Proposed average pressure reduction**

<table>
<thead>
<tr>
<th>Zone</th>
<th>66M</th>
<th>75M</th>
<th>140M</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proposed daily average pressure reduction</td>
<td>10m</td>
<td>21m</td>
<td>19m</td>
</tr>
<tr>
<td>% of pressure reduction at AZP</td>
<td>17%</td>
<td>30%</td>
<td>19%</td>
</tr>
</tbody>
</table>
Operating mode
To address some specific conditions of operation (such as fire fighting or exceptional demand conditions), a closed loop control system can be implemented for additional security. The PRV will open more when requested to do so by the control loop sensors located downstream in the network. It has been estimated that roughly 18 control loop sensor locations are required to cover the three zones. The exact number and locations of these sensors should be designed during a detailed study, after a complete firefighting test is conducted.

EXPECTED OUTCOME: NPV AND PAYBACK PERIOD CALCULATIONS

The simple payback period of the project was calculated by assessing the implementation costs versus the expected savings.

Costs Analysis
Cross connections (CCs) costs
The hydraulic modeling exercise highlighted 61 new CCs required for the three new zones. The diameter of each CC was assumed to be the smaller of the two offtakes. Each CC location was assessed against the GIS background to evaluate the main elements that would impact the construction costs: the required pipework length, the traffic density (main road or back street) and the nature of the intersection with roads (sidewalk works, CC crosses 1 lane, full road works). The construction cost of each CC was then calculated using SA Water's contractor Schedule of Rates (SOR).

Lock Stop Valves (LSVs) costs
For the definition of the three new zones, the modelling exercise identified 33 new valves to be installed and 227 existing valves to be operated (to be closed or reopened). Based on operational experience, it is known that a portion of the 227 valves would require replacement due to valves leaking or being inoperable. For this project cost estimation, it was assumed that 50% of these 227 valves would require replacement, which was deemed conservatively high. The purchase and installation costs of each valve were then calculated using the SOR.

PRVs costs
11 new PRVs have been identified to supply the three new zones. The estimation for each PRV installation was prepared following two potential layouts: PRV building and PRV chambers. Potential costs for easement or land acquisition were calculated where required, based on the results of the field investigations. The estimation included fees associated with civil, electrical, mechanical, SCADA works, as well as project design and management fees.

Operational Expenditure
Operational Expenditure (OPEX) for this project was assumed as 1% of the Capital Expenditure (CAPEX).

Cost summary
Table 4 presents a summary of the expected CAPEX per zone:

<table>
<thead>
<tr>
<th>Expected CAPEX (K$)</th>
<th>EL66M</th>
<th>EL75M</th>
<th>EL140M</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1,050</td>
<td>3,050</td>
<td>6,550</td>
</tr>
</tbody>
</table>

Benefits Analysis
Three main benefits are expected from implementing pressure modulation, with associated savings:
- Leak flow reduction and associated savings on water production costs;
- Burst reduction and associated savings on repair costs; and
- Asset life extension and associated CAPEX deferral.

Each of these savings will be calculated using data available in the literature.

Savings associated with leak flow reduction
Thornton & Lambert (2001) define the relationship between the pressure in a network and the leakage flow rate of that network by the N1 power law.

Losses for the whole Adelaide Metro as reported by SA Water (Kumar, 2013) are estimated to be 10%. No metering zones for losses are currently implemented in the Adelaide Metro network, therefore, it is not possible to assess the losses per area. However, it can be expected that in areas exhibiting a high burst rate, losses will be higher. Therefore, it was decided to estimate the losses for each modulated zone by applying the same ratio as the burst ratio (zone/whole network). The consumption per zone was extracted from the customer service database based on five years of historical data. Losses were then calculated as a percentage of this consumption.

The ratio of rigid pipes was calculated from the GIS pipework database, extracted for each zone. Using the N1 power law and the expected pressure decrease in each zone calculated earlier in the study, a yearly volume of water savings was calculated for each zone and converted into dollars using an SAW average water production cost.

Benefits associated with burst reduction
As per Figure 2 (Thornton & Lambert (2007)), reduction in pressure is directly correlated to a reduction in burst frequency, both on pipelines and service connections.
Figure 2: Reduction of Max Pressure vs Reduction of Bursts

To categorise the expected level of impact of pressure reduction implementation (between very low and very high), the Burst Frequency Index (BFI) for water mains was calculated for each zone. This resulted in an expected low, high and high impact for the EL66M, EL75M and EL140M zones respectively. By using the predicted pressure decrease and the above graph, the forecast reduction in burst on mains is expected to be 11% for the EL66M, 60% for the EL75M and 46% for the EL140M. This burst reduction rate was then converted into dollars using average repair costs.

The same exercise was undertaken for leaks on service connections.

Benefits associated with assets life extension
Lambert & Thornton (2012) provide data for the average years to failure vs. maximum pressure for AC pipes DN100 to DN300. Lambert & Thornton (2012) also describe a method for “assessing the financial benefit (in terms of Net Present Value (NPV)) of extending asset life by pressure management.”

“The Financial Benefit of deferring replacement of a section of AC main by EP years, when the assumed Residual Life is RL years, for discount rate r% and interest rate i%, can be calculated in terms of Net Present Value (NPV) from the equation:

\[ NPV = RCo \times K^{RL}(1 - K^{EP}) \]

Where

\[ K = (1 + i%) / (1 + r%) \]

RCo: cost/metre of replacing AC mains”

Values for the Adelaide Metro network were calculated considering a discount rate of 5.06% and an interest rate of 2.5%. Cost for water main relays were taken as standard 2014 costs for each DN class.

Within each modulated zone, the GIS database was analysed to calculate the residual life (RL) for each length of pipework, for each type of material, and considering a total asset life of 80 years for AC pipes, 135 years for DI pipes and 70 years for PE pipes.

The expected life extension EP for each class of AC diameter below DN300 was calculated using Lambert & Thornton (2012) data and the expected pressure decrease in each zone.

Using the NPV formula above, a NPV was hence calculated for each DN and age class for AC mains. As no data was present in the literature for CI/DI pipes, a similar trend was assumed for CI/DI life extension with respect to pressure decrease. A NPV was hence calculated in the same way for all CI/DI pipes below DN300.

For PE pipes, the expected asset life increase versus a reduction in pressure was calculated using Suez Environnement research results. Applying the same formula, a NPV was calculated for all PE pipes.

The same exercise was completed for the PE service connections, assuming a current average age of 15 years (insufficient GIS data available) and an estimated asset life of 40 years.

Other benefits
Some additional savings expected from the pressure modulation were not included in the payback calculation as they are difficult to quantify. However, they do represent a real benefit to SA Water, mostly in terms of customer satisfaction increase and company image improvement:

- Reduction in secondary damages and resulting liabilities (burst related);
- Reduction in unplanned service interruptions (burst or burst repair related);
- Less disturbance to community from works (burst repair related);
- Reduction in water quality complaints (burst related, due to flow reversal or velocity increase); and
- Improvement to company image due to less burst related presence in the newspapers.

Benefits summary
Table 5 presents a summary of the expected savings per zone:

<table>
<thead>
<tr>
<th></th>
<th>EL66M</th>
<th>EL75M</th>
<th>EL140M</th>
</tr>
</thead>
<tbody>
<tr>
<td>Savings on water</td>
<td>55</td>
<td>400</td>
<td>730</td>
</tr>
<tr>
<td>and bursts</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(K$AUD/year)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Savings on asset</td>
<td>2,800</td>
<td>4,500</td>
<td>7,550</td>
</tr>
<tr>
<td>life (K$AUD)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Simple payback period and NPV calculation

Using the costs and savings calculated above, Table 6 displays the simple payback calculation as well as the NPV calculation (considering a cost of capital of 5.06%) for the three zones and for the project as a whole. Note that the asset deferral savings were not integrated in the simple payback calculation. All numbers should be confirmed during the design phase.

Table 6: Simple payback and NPV

<table>
<thead>
<tr>
<th></th>
<th>EL66M</th>
<th>EL75M</th>
<th>EL140M</th>
<th>Whole project</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple payback (years) (no asset deferral)</td>
<td>23.1</td>
<td>8.2</td>
<td>9.9</td>
<td>9.8</td>
</tr>
<tr>
<td>NPV (K$) (with asset deferral)</td>
<td>2,400</td>
<td>7,000</td>
<td>10,950</td>
<td>20,400</td>
</tr>
</tbody>
</table>

**CONCLUSION**

The feasibility study was undertaken to assess the potential for pressure management in the Adelaide Metropolitan area. The study demonstrated that there are opportunities to do so, and a general assessment of the network highlighted several promising areas. As a result, three new pressure zones have been proposed within existing zones. Served by 12 PRVs, these new zones would cover 19% of the Adelaide network length, 18% of the water meters and 28% of the bursts that have previously occurred on water mains. The potential for a decrease in pressure is estimated as 20m for two of the zones, and 10m for the third.

CAPEX associated with the proposed network reconfiguration (new PRVs, new cross connections, new valves) has been estimated at $10,650K. Expected benefits have been estimated at $1,185K/year associated with savings on leakage volume and burst repairs, and $14,850K associated with the extension of asset life.

Of the three proposed modulated zones, EL75M is the one with the fastest Simple Payback and the greatest NPV. Simple Payback (excluding the asset deferral) for the whole project is estimated at just under 10 years. The NPV for the whole project, including the asset deferral is expected to reach $20,400K.

**ACKNOWLEDGMENT**

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