INTERPRETATION OF LOGGING RESULTS AS A WATER NETWORK PROBLEM-SOLVING TOOL

Report to the
Water Research Commission

by

N Meyer & CJ Seago
WRP Consulting Engineers

WRC Report No. TT 737/17
ISBN 978-1-4312-0915-6

November 2017

Obtainable from

Water Research Commission
Private Bag X03
Gezina, 0031

orders@wrc.org.za or download from www.wrc.org.za

DISCLAIMER

This report has been reviewed by the Water Research Commission (WRC) and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the WRC, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

Printed in the Republic of South Africa

EXECUTIVE SUMMARY

Operational problems in municipal water networks can in some cases be difficult and time-consuming to resolve. Such problems can include, but are not limited to, areas with unexplained high or low water pressure, areas with erratic/fluctuating pressures, reservoirs that either run dry or overflow, or unexplained connections between two apparent discrete pressure zones. Few municipalities are equipped to resolve such problems quickly and efficiently. In many municipalities, the problem is also exacerbated by insufficient personnel and budgets for operation and maintenance.

Operational staff should be equipped to identify and resolve water-related operational problems quickly and efficiently. This will improve customer satisfaction, prolong infrastructure life and reduce water wastage.

The objective of this document is to provide a guideline for municipalities to identify and resolve several different operational problems in water reticulation systems by logging pressures and flows and interpreting those logging results.

Section 1 gives the background and objective of the report. Section 2 describes some of the key aspects relating to pressure and flow logging in a water reticulation network:

- Description of logging.
- Reasons why logging data is obtained.
- Typical flow- and pressure-logging data graphs and important terminology.
- Types of logging equipment.
- General guidelines for programming and installation of logging equipment.

Section 3 provides detailed procedures to investigate and resolve some common operational problems in water networks. Case studies are included with locality maps, actual logging results and supporting information such as photos and diagrams. The problems discussed are:

- High/low-water pressure complaints.
- Open cross-boundary connections.
- Reservoir overflow.
- Blocked strainers.
- Erratic water pressure.
- Consumer leakage.

Section 4 provides a summary guideline that can be used to plan the investigation and remedial action to resolve some common operational problems in water networks.

ACKNOWLEDGEMENTS

The authors would like to thank the WRC for funding the project, and for assisting the project manager throughout the duration of the project. In addition, the author would like to thank the following individuals for their valuable input:

- Trevor Westman – Deputy Director, Water Demand Management, City of Tshwane.
- Nico Schmulian – Functional Head, Water Demand Management, City of Tshwane.
- Petrus Swart – Senior Technician, WRP Engineers.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

kl	**:**	kilolitre = cubic metre = m^3 = 1000 litre
m	**:**	metre (10 metre water pressure = 1 bar)
Ml	**:**	megalitre = 1000 kilolitre = 1000 m^3
MNF	**:**	Minimum Night Flow
m^3	**:**	cubic metre = kilolitre = kl = 1000 litre
PRV	**:**	Pressure-reducing Valve
PRV D/S	**:**	PRV Downstream
PRV U/S	**:**	PRV Upstream
WRC	**:**	Water Research Commission of South Africa

Page left blank intentionally

1 INTRODUCTION

1.1 Background

Operational problems in municipal water networks can in some cases be difficult and time-consuming to resolve. Such problems can include, but are not limited to, areas with unexplained high or low water pressure, areas with erratic pressures, reservoirs that either run dry or overflow, or unexplained connections between two apparent discrete pressure zones. Few municipalities are equipped to resolve such problems quickly and efficiently. In many municipalities, the problem is also exacerbated by insufficient personnel and budgets for operation and maintenance.

Operational staff should be equipped to identify and resolve water-related operational problems quickly and efficiently. This will improve customer satisfaction, prolong infrastructure life and reduce water wastage.

1.2 Objective

The objective of this document is to provide a guideline for municipalities to identify and resolve several different operational problems in water reticulation systems by logging pressures and flows, and interpreting those logging results.

2 GENERAL OVERVIEW OF LOGGING

This section describes some of the key aspects relating to pressure and flow logging in a water reticulation network:

- What is logging?
- Why is logging data obtained?
- Typical flow- and pressure-logging data graphs and important terminology.
- Types of logging equipment.
- Event-based versus time-based flow logging.
- How to log?

2.1 What Is Logging?

Logging refers to the procedure of recording data (such as flow, pressure and level) at regular intervals using mechanical chart recorders or electronic logging devices, which are referred to as data loggers.

In this document, the focus is on using electronic data loggers and interpreting logging data. In a water network, flow logging is undertaken by connecting a data logger to a water meter. Pressure logging is undertaken by connecting a data logger to a fire hydrant, tap or by pressure tapping (see Figure 1). The data on the logger can be downloaded onto a computer for analysis, as highlighted in Section 2.2, which outlines why logging data is obtained.

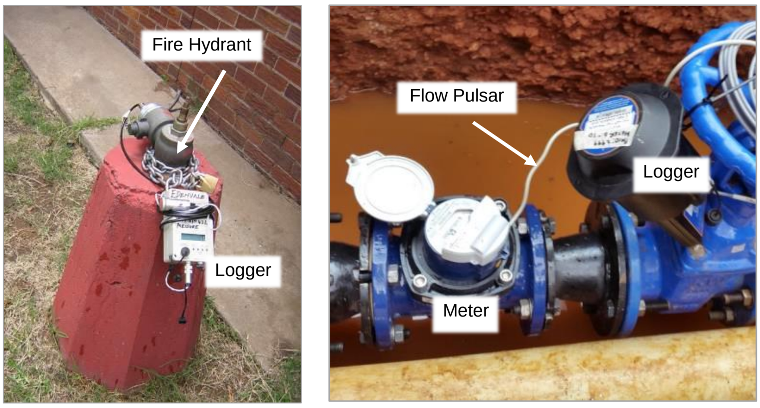


Figure 1: Electronic data loggers used for pressure logging (left) and flow logging (right)

2.2 Why is Logging Data Obtained?

2.2.1 Flow-logging data

Flow-logging data is typically used:

- To determine the flow profile of a water management zone or a consumer.
- To determine the minimum night flow for leakage analysis.
- To determine the size of a new meter, pressure-reducing valve (PRV) or pipeline.
- To undertake a peak factor analysis. The peak factor is the ratio between the maximum flow rate and the average flow rate over an extended time period.

2.2.2 Pressure-logging data

Pressure-logging data is typically used:

- To determine the pressure distribution throughout a zone.
- To determine the extent that pressures vary over time.
- To check the functionality of PRVs or pumps.
- To detect possible unknown restrictions in a water network.
- To test zone discreteness and locate possible cross-boundary connections.
- To evaluate the potential for pressure management. Leakage is driven primarily by pressure. If the pressure can be reduced, leakage will reduce. More information on pressure management analysis can be obtained in the Presmac User Guide (McKenzie, 2001).

2.3 Typical Logging Data Graphs and Important Terminology

Flow- and pressure-logging results are best interpreted when plotted on a graph with the Y-axis representing either pressure (e.g. metres, bar) or flow (e.g. cubic metres per hour, litres per second), and the X-axis representing the time period. The area under the flow graph represents the total volume over the time period. A typical graph is shown in Figure 2.

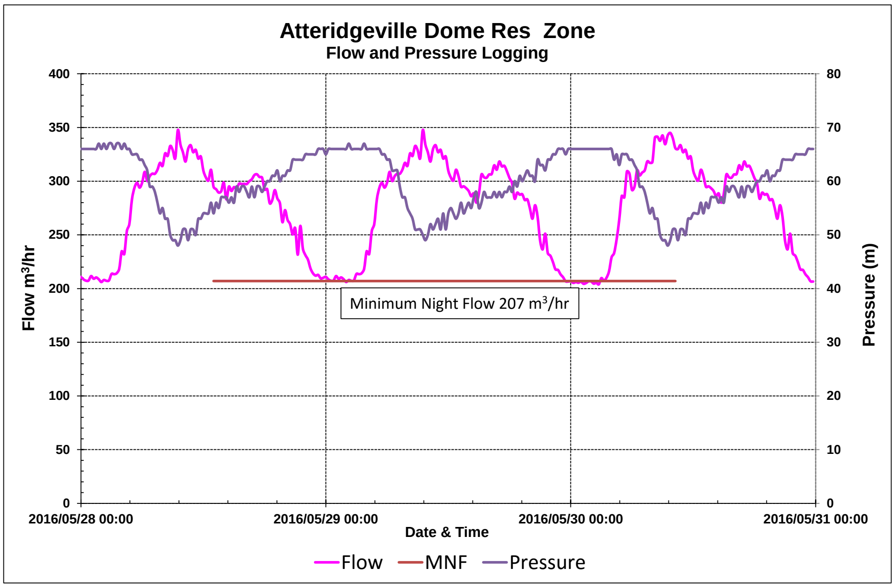


Figure 2: Typical flow- and pressure-logging example

Where both pressure and flow logging results are available, it is recommended to plot them over the same time period, which allows for better interpretation of the data. Flow is usually logged at the inlet of a zone or on the supply to a consumer, and indicates flow rate and volume of water used over time.

The expected flow profile would usually show higher flows in the daytime (when consumers are using water), and lower flows at night-time (when consumers are asleep).

The minimum night flow (MNF) is read off the flow graph as the minimum value that occurs over the logging period. This usually takes place between about 01:00 and 03:00 each day. A stable MNF (meaning a flow that recurs consecutively for several days) is normally a clear indication of leakage. More information on night flow analysis can be obtained in the Sanflow User Guide (McKenzie, 1999).

Terminology:

MNF: **Minimum night flow** is the minimum flow recorded over the logged time period, usually daily between 01:00 and 03:00. A stable minimum night flow is normally a clear indication of leakage.

Did you know?

Pressures are usually lowest in the daytime and highest at night. Conversely, normal flow profiles show highest use in the day, and lowest use at night.

Pressures can be logged at several varying points throughout a reticulation system. Conversely to flow, pressure is usually at its lowest during the daytime (dynamic pressure) and highest in the early hours of the morning (static pressure) at the time when the MNF occurs. When assessing the functionality of a PRV, points just upstream and downstream of the PRV are logged. A correct functioning PRV should show a stable pressure on the downstream side regardless of variations in flow or upstream pressure.

Terminology:

Static pressure is the pressure measured when there is zero flow in the water network. Water networks always have leakage. Therefore, the pressure in a water network will usually not reach the full static pressure level. The maximum pressure at night (when flow is at the minimum) is normally referred to as the static pressure. In a reservoir zone, the theoretical static pressure at a hydrant/tap will be equal to the elevation difference between the reservoir top water level and the hydrant/tap in question.

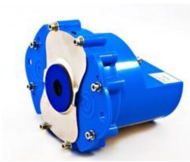
Dynamic pressure is normally referred to as the pressure in the water network when flow is at a maximum.

2.4 Logging Devices and Other Necessary Equipment

2.4.1 Data loggers

Some of the data logger types used in South Africa are shown in Table 1.

Table 1: Data loggers

Technolog **www.technolog.com**	**Sensus** **www.sensus.com**	**Radcom** **www.hwmglobal.com**	**MyCity** **www.flotron.co.za**
			

Over and above the logging device, additional equipment is required to log flows and pressures. Examples of flow- and pressure-logging equipment are shown in Table 2 in Table 3.

2.4.2 Flow-logging equipment

Flow data can be collected either digitally from water meters (generally via a pulsar fitted to the meter register) or via analogue connections to meters that emit an output signal between 4 mA and 20 mA (such as electromagnetic water meters). The latest models of electromagnetic water meters can also be configured to provide a digital pulse output. This report only discusses digital flow logging on mechanical meters.

Table 2: Flow-logging equipment

Reed switch pulsar 	The reed switch type pulsar is an electrical switch that is activated by an applied magnetic field. It consists of a pair of contacts on metal reeds, which are housed in a sealed glass envelope. The water meter register contains a rotating magnet. When the magnet rotates past the reed switch, it causes the reeds to connect. This closes an electrical circuit and creates a pulse. The value of the pulse (e.g. 1 m^3, 0.1 m^3, 0.0001 m^3) depends on the position where the reed switch is inserted into the water meter. Normally two reed switch positions are available. The value of the pulse at each position is fixed and is dependent on the meter size and model.

Optical pulsars 	The optical pulsar is a device comprising a photo emitter and a photodetector. The water meter register contains a rotating mirror wheel that reflects infrared light. A pulse is created when the mirror causes a break in the light detected by the photodetector. This pulsar can identify forward and reverse rotation, making it possible to record forward and reverse flow through the water meter. The pulse value is fixed and is based on the meter size. Normally, there is only one position available on a meter register for this pulsar.
Inductive pulsars  	The inductive pulsar has a sensor that detects the rotation of a pointer on the meter register. The pointer is a metal disk, shaped in a half moon, which rotates when water passes through the water meter. The rotation direction of the pointer enables the inductive pulsar to distinguish between forward and reverse flow. The pulse value for this pulsar is printed on the pulsar. The pulsar is selected based on the meter size and expected flow rate.
Hybrid meters 	The hybrid register is normally an electronic register that includes an integrated communications cable. This can be used for a wide range of standard outputs compatible with common automatic meter reading systems and data-logging equipment. The pulse output from this water meter is obtained through the integrated communication cable. The pulse value is fixed for the specific meter register.

2.4.3 Pressure-logging equipment

Table 3: Pressure-logging equipment

Pressure transducer   **External transducer internal transducer**	Pressure data is collected via an analogue input port from an external or internal pressure transducer. A pressure transducer is a device that converts an applied pressure into a measurable electrical signal. A pressure transducer consists of two main parts: an elastic material that deforms when exposed to a pressurised medium, and an electrical device that detects the deformation.

<table>
<tr><td>Tap connection fittings
</td><td>A tap connection fitting can be made by using commercial garden tap connectors with a combination of galvanised or brass fittings. The tap connection fitting can be used to connect a pressure gauge or a pressure transducer to a tap or any similar threaded connection.</td></tr>
<tr><td>Hydrant caps
</td><td>A hydrant cap is a fitting that is used to connect a pressure gauge or a pressure transducer to a fire hydrant.
Pressure logging at a hydrant is preferred over logging at a consumer tap since the pressure logged at a consumer tap is influenced by water usage elsewhere on the property (e.g. flushing toilets).</td></tr>
</table>

2.5 Event-based Versus Time-based Flow Logging

Digital flow data can be obtained in either:

- Type A: Time-based logging.
- Type B: Event-based logging.

In both cases, the connection between the water meter and the data logger is similar but the method used to store the data varies. For Type A loggers, the real-time clock built into the logger counts the number of pulses received in constant intervals determined by the user. Since the value of a pulse is known (e.g. 1 m^3/pulse), the total volume that pass through the meter during each interval can be calculated. Thus, the flow rate can easily be calculated for each timed interval.

For Type B loggers, the logger is triggered by the flow of water through the water meter and the time between pulses is recorded. Since the value of a triggering pulse is known (e.g. 1 m^3/pulse), the flow rate can be determined.

Both Type A and Type B logging systems have advantages and disadvantages. In various situations one type may perform better than the other. Time-based flow logging can typically be used where general flow profiles are required. Event-based flow logging can be used where specific events (such as spikes in the flow profile) are to be investigated. Since the internal electronic layout of the two types do not differ greatly, it is not difficult for manufacturers to incorporate both measurement systems.

2.6 How to Log?

Logging can be undertaken through the following general steps:

- Select a data logger and obtain the necessary software and user manuals (refer to Section 2.6.1). Consider if event-based or time-based flow logging is required, and select the data logger accordingly (refer to Section 2.5).
- Obtain the required flow- and pressure-logging equipment (refer to Section 2.4).
- Follow the logger manufacturer's user guideline to program the logger.

- Install the logger:
    - For flow logging, this involves installing a flow pulsar on the meter and connecting the pulsar to the logger (refer to Section 2.4). Further information on selecting and installing flow pulsars can be obtained from meter manufacturers.
    - For pressure logging, this involves installing a pressure transducer on a hydrant cap or tap, or by pressure tapping and connecting the pressure transducer to the logger (refer to Section 2.4).
- Consider the logging tips as discussed in Section 2.6.2, Section 2.6.3 and Section 2.6.4.

2.6.1 Software used for programming loggers

The software used to programme loggers is hardware specific and must be obtained from the manufacturer/supplier of the logger. User manuals are supplied with the software and provide a step-by-step guide on how the loggers should be programmed and downloaded. Loggers are typically connected to a computer via a connection cable; however, the connection could also be through Wi-Fi or Bluetooth.

2.6.2 General logging tips

If time-based logging is used, the logging interval should be selected to suit the purpose of the logging exercise. If general flow or pressure profiles are required, a 15-minute logging interval is normally suitable. If sudden changes in pressure are expected, it may be required to log at intervals of one minute or one second. If event-based logging is used, the logging interval is not required since each event will be logged.

When the data is analysed afterwards, it is often summarised to a fixed time interval to better display the data line on the graph. The data view would then be similar to that of a time-based logging.

Before leaving the site, it should be confirmed that the logger is operational and recording data. Loggers should preferably be placed as high as possible on the walls of a chamber in case the chamber floods.

Cable ties should be used to neaten the flow- and pressure-logging cables to reduce the risk of cable damage when personnel enter the chamber.

2.6.3 Flow-logging tips

Most water meters have the facility to provide a pulse output that can be logged. A pulse is generated each time a certain volume of water passes through the meter. The pulse value used to program the logger should be the same as the pulse value obtained from the meter (typically 0.001 m^3/pulse, 0.01 m^3/pulse, 0.1 m^3/pulse, 1 m^3/pulse, or 10 m^3/pulse). If these pulse values differ, the logging data will be incorrect.

It is recommended that the meter readings are recorded when installing or removing a logger. The difference between the end and start meter reading should be compared to the total recorded volume logged over the same period. If the volumes obtained from the meter readings and that from the logger are the same, then it confirms that the logging has been successful. If these volumes differ, the logging has not been successful and further investigation is required. It may be required to use a different flow cable or logger, or to replace the meter or meter register.

2.6.4 Pressure-logging tips

Pressure transducers should be calibrated at least once a year. When a pressure logger is installed, the pressure should also be checked with a calibrated pressure gauge. If the logger gauge and the pressure gauge give the same pressure reading, it confirms that the pressure transducer is accurate (at least at the recorded pressure level).

There should be no water leaks on the hydrant or tap coupling, which is used for pressure logging. If there are leaks, pressure logging may be affected.

3 INVESTIGATING TYPICAL OPERATIONAL PROBLEMS

This section provides a detailed procedure to investigate and resolve some common operational problems in water networks. Case studies are included with locality maps, actual logging results and supporting information such as photos and diagrams.

3.1 High/Low Pressure

3.1.1 Background

This section focuses on high/low water pressure caused by operational problems in the water network. In the preparation of this section it was assumed that the water pressure in the area investigated has been acceptable under normal operating conditions and that some operational problem has caused the high/low water pressure. The approach, therefore, does not cover high/low-pressure problems caused by network/infrastructure limitations.

Low water pressure in reticulation networks is one of the most common problems reported to operational and maintenance personnel. Many factors cause or contribute to low pressures, ranging from burst pipes, closed network valves, open zone boundary valves, blockages in the network or on consumer connections, incorrectly set PRVs, or insufficient water in reservoirs. Most operational problems can easily be identified through basic site inspections such as checking reservoir levels, checking if a consumer meter is blocked, confirming inlet and outlet pressures at a PRV, or checking for burst pipes in the network. Some of the problems such as closed network valves, undetected below-ground leaks or blockages in the network are, however, more difficult to locate. These problems require a systematic fault-finding approach to identify and solve. The municipality is normally made aware of a low-pressure problem through customer complaints.

High water pressure can be caused by an open zone boundary valve, incorrectly set PRV or by a malfunctioning PRV or pump. The municipality is normally made aware of a high-pressure problem through an increase in burst pipes.

3.1.2 Approach

The following tasks can be undertaken to identify and resolve the causes of low water pressure. The tasks in Table 4 are shown more or less in the order they can be undertaken; however, the order can be changed depending on the specific situation.

Table 4: Resolving low water pressure issues

Task	Description
Undertake visual inspections	Before detailed investigations are undertaken, it is recommended to start with basic visual inspections to confirm if the pressure is low and to check if there are obvious causes for the low pressure. These basic checks can include (but are not limited to): • Use a gauge to check pressure at the point of the low-pressure complaint and confirm if there is a low-pressure problem or not. • Check if the consumer meter(s) in the area with low pressure is blocked. Blocked meters must be cleaned out or replaced. • Check if there are significant visual leaks in the network. All visual network leaks must be repaired. • Confirm if there is sufficient water in the relevant reservoir/tower. • If there is a PRV on the supply to the affected area, confirm if the upstream and downstream pressures at the PRV are in line with the expected pressures. If the PRV setting has been lowered, it can be adjusted to the correct setting. If the PRV setting is however correct, no further adjustments should be made to the PRV at this stage since the cause of the low pressure is then downstream of the PRV. • Confirm that the zone boundary valves for the affected zone are closed properly. If boundary valves are not closed, it could result in either unwanted high or low water pressure in the affected zone. If some boundary valves do not seal properly, they should be replaced.

<table>
<tr><th>Task</th><th>Description</th></tr>
<tr><td>Evaluate pressures on hydraulic model</td><td>If no obvious cause for the low pressure has been identified, more information needs to be collected about the nature of the problem. It is useful to obtain the theoretical static and dynamic pressures from a hydraulic model and to compare the theoretical pressures with the actual pressures. If the theoretical pressures are higher than the actual pressures, further field investigation should be undertaken.

Many municipalities in South Africa already have hydraulic models. If there is no such model, the municipality should be encouraged to develop one.</td></tr>
<tr><td>Log pressure at the point of the low pressure and the inlet of the zone</td><td>A pressure logger can be installed on a fire hydrant, pressure tapping or tap in the affected low-pressure area and also at the inlet to the zone. Evaluating the pressure-logging results provides an indication of what the cause of the low pressure could be:
If the pressure is acceptable at the zone inlet and lower than expected at the affected area, it is clear that there is a problem between the inlet point and the affected area.
If only the dynamic pressures in the affected area are lower than expected and the static pressures appear normal, it is normally an indication that there is one or more restriction(s) between the supply point and the affected area that is creating pressure loss.
If the static pressure in the affected area is also lower than expected, it could be an indication that the zone boundary has been altered or that there is still a significant leak or open boundary connection in the zone.
If the pressure at the inlet point to the zone is lower than expected, then the problem is upstream of the zone inlet point.</td></tr>
<tr><td>Do detailed pressure checks</td><td>If the problem cannot be located and resolved with the above-mentioned tasks, further detailed investigations can be undertaken. The detailed investigations can include the following steps:
Highlight large diameter mains on a layout drawing.
Undertake pressure checks by starting at the zone inlet and working towards the area with low pressure. For the first round, undertake pressure checks as close as possible to the bulk mains and mark the gauge pressures on a drawing. The gauge pressures should be compared against the theoretical pressures from the hydraulic model. Investigate any significant differences between the gauge pressures and theoretical pressures investigated in a second round of pressure checks.
In the second round of pressure checks, the aim should be to identify more precisely at which point(s) significant pressure changes occur. Once this point(s) has been located, the restriction or other cause of low pressure should be checked:
Confirm that all isolating valves in the vicinity are fully open. Expose buried valves. Replace non-operational valves.
Inspect the drawing and compare it against what is found on-site. There are many examples of differences between as-built drawings and what is found on-site. These differences could include missing pipes or missing connections between pipes.
If it is established that the pressure drop is in all likelihood due to a restriction in the pipe or an undetected below-ground leak, then a ground microphone can be used to locate the problem.</td></tr>
</table>

The tasks in Table 5 can be undertaken to identify and resolve the causes of high water pressure.

Table 5: Resolving high water pressure issues

Task	Description
Undertake visual inspections	Before detailed investigations are undertaken, it is recommended to start with basic visual inspections to confirm if the pressure is high and to check if there are obvious causes for the high pressure. These basic checks can include (but are not limited to): • Use a gauge to check pressure at the point that has the high pressure and confirm if there is a pressure problem or not. • If there is a PRV on the supply to the affected area, confirm if the setting on the PRV is correct. If the PRV setting has been increased, it can be lowered to the correct setting. If the PRV malfunctions, it should be serviced and recommissioned. • If there is a pump on the supply to the affected area, confirm if the pump outlet pressure is correct. If the pump malfunctions, it should be serviced. • Confirm that the zone boundary valves for the affected zone are closed properly. If boundary valves are not closed, it could result in either unwanted high or low water pressure in the affected zone. If some boundary valves are not sealing properly, they should be replaced. The checks listed above should be sufficient to solve most high-pressure problems. If no obvious cause for the high pressure can be identified, further detailed tasks can be undertaken similar to the low-pressure investigation (logging of pressures and doing detailed pressure checks).

3.1.3 Case Study 1: Kewtown (City of Cape Town)

Figure 3: Locality map of Kewtown

Commented [Ed1]:

The case study is from the residential suburb of Kewtown in the City of Cape Town municipality. In 2010, the City of Cape Town implemented pressure management in the existing network. This involved constructing two PRV installations as well as closing a number of boundary valves. The area is flat with only a few metres difference in elevation between the highest and lowest point. Once the project was completed and the PRVs set, various low-pressure complaints were lodged by consumers in the area, which is marked in yellow on the map in Figure 3. The approach followed to identify and resolve the problem is given in Table 6.

Table 6: Approach to fix low-pressure complaints in Kewtown

Task	Outcome/Conclusion
Do visual inspections	• No blockages were found in a sample of consumer meters checked. • The upstream and downstream pressures were found to be correct for both PRVs. • No obvious visual leaks were observed in the area of the low-pressure complaints. • All the zone boundary valves were found to be closed.
Review hydraulic model	The area is flat with only a few metres difference in elevation between the highest and lowest point. According to the hydraulic model, the pressures at the complaint area should have been similar to the outlet pressure of the PRVs.
Log pressure	Pressure logging was undertaken at the PRVs and at the complaint area. The initial pressure-logging graph is shown in Figure 4. The static pressure at the complaint area appeared normal; however, the dynamic pressure at this point was significantly lower than expected. It was therefore deduced that there was an obstruction between one of the PRVs and the complaint area.
Do detailed pressure checks	A layout drawing of the reticulation system was used and the large diameter mains were highlighted. Planned pressure checks were undertaken close to the large diameter mains at regular distances between the PRVs and the complaint area (see Figure 5). A large discrepancy was found between Point E and Point F (see Figure 5) where the pressure changed from high (65 m) to medium (35 m) over a short distance.
Locate problem	Further discussions with the operational personnel revealed that the 225 mm diameter pipe in Appledene Road was capped years ago between Point E and Point F (See Figure 5). The capped pipe position was not shown on the drawings. Before the pressure management project has been implemented, the capped pipe did not cause any pressure problems because of the redundancy in the system. When the zone boundary valves were closed, however, it reduced the redundancy and the low-pressure complaints highlighted that there was a problem in the zone. Terminology Redundancy is the term used when more than one pipe can supply a section in a water distribution network. The higher the number of pipes that can supply a section, the higher the network redundancy.
Resolve the problem	The operational team subsequently installed a new section of pipe (where it was capped) and this immediately resolved the low-pressure problem. The final logging period on Figure 4 shows the pressures in the zone after the problem was resolved. The PRV setting was lowered to 55 m and the large fluctuation between static and dynamic pressure at the complaint area was no longer present. The PRV setting was to be further reduced at a later stage.

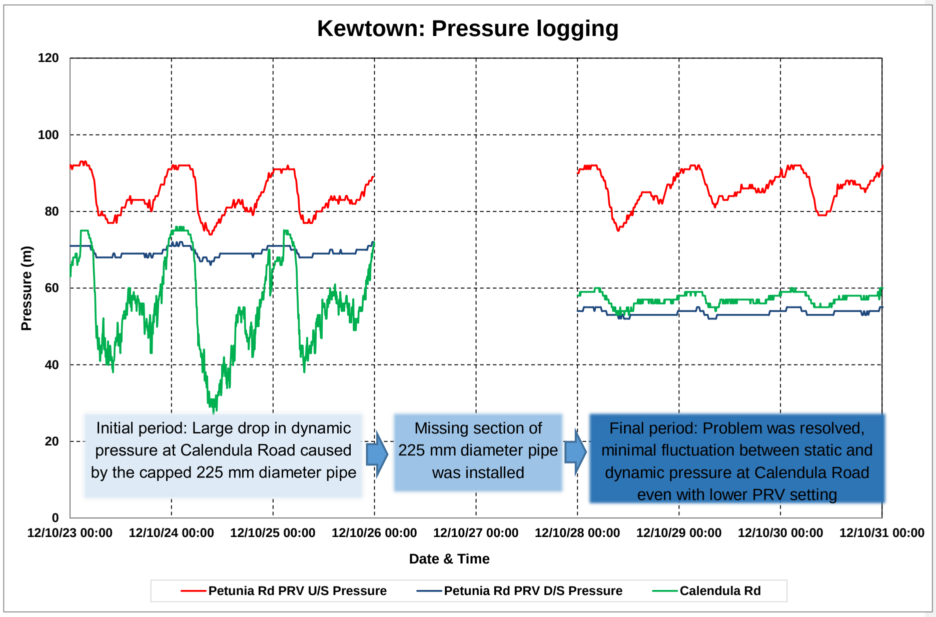


Figure 4: Pressure-logging graph: Kewtown

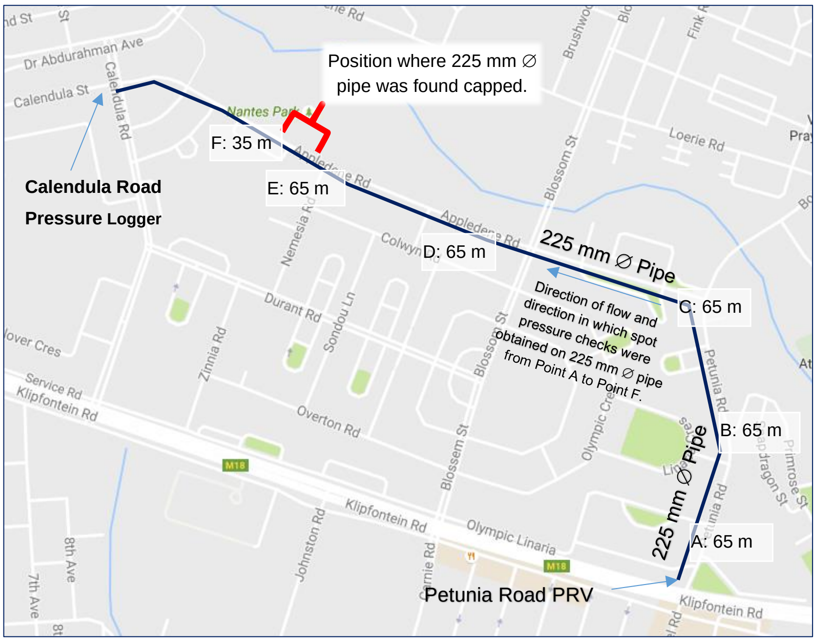


Figure 5: Planned pressure checks were used to locate the problem: Kewtown

A large discrepancy was found between Point E and Point F where the pressure changed from high (65 m) to medium (35 m) over a short distance. Further discussions with the operational personnel revealed that the 225 mm diameter pipe in Appledene Road was capped years ago between Point E and Point F.

3.1.4 Case Study 2: Valhalla PRV (City of Tshwane)

The case study is from the Valhalla PRV zone in the City of Tshwane municipality. The Valhalla PRV is located on a take-off point from the bulk line that supplies the Valhalla Reservoir. In October 2016, complaints were received from consumers in the Valhalla PRV zone who indicated that the pressure was very low during certain periods of the day. There were already permanent GSM loggers at the PRV as well as the critical point of this zone, and the logging data was relayed to a web-based monitoring system. The logging data was analysed to identify the cause of the problem.

Did you know?

Permanent GSM loggers can be useful to monitor long-term trends in flow and pressure. GSM loggers can also be used to trigger alarms to notify the user when the flow or pressure changes significantly.

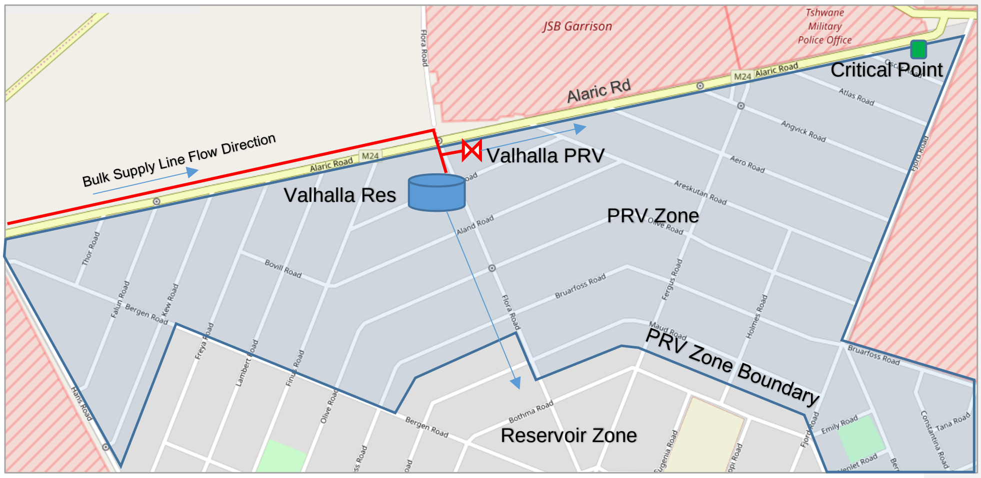


Figure 6: Locality map of Valhalla PRV zone

The approach followed to identify and resolve the problem is given in Table 7.

Table 7: Approach to fix low-pressure complaints in Valhalla

Task	Outcome/Conclusion
Do visual inspections	Logging data was already available. It was decided to analyse the logging data before determining if any visual inspections should be undertaken.
Review hydraulic model	According to the hydraulic model, the pressures at the complaint area should have been higher than the logged pressure in October 2016.
Log pressure and flow, and analyse logging data	Based on the available pressure-logging data shown in Figure 7, it was clear that the PRV upstream pressure decreased during certain hours of each day, which was the cause of the low pressures in the PRV zone. The periods at which the upstream pressure decreased did not correlate with the normal peak flow periods of the Valhalla PRV zone. It was therefore concluded that the drop in upstream pressure was caused by an external factor.
Log pressure and flow, and analyse logging data (continued)	The Valhalla PRV is located on a take-off point from the bulk supply line to the Valhalla Reservoir. The inlet meter of the Valhalla Reservoir also had a permanent logger. Flow-logging data for this meter was plotted on the same graph as the Valhalla PRV zone pressures. Figure 8 clearly shows that the decrease in upstream pressure at the Valhalla PRV coincided with the periods when there was inflow into the Valhalla Reservoir. By comparing the reservoir inlet flow to that of previous periods, it was established that the reservoir inflow was much higher than before. Therefore, the high reservoir inflow was most likely the cause of the pressure problem at the Valhalla PRV. Further inspection revealed that the reservoir inlet control valve was incorrectly set. A recommendation was subsequently made to the City of Tshwane to adjust the setting on the reservoir inlet control valve.

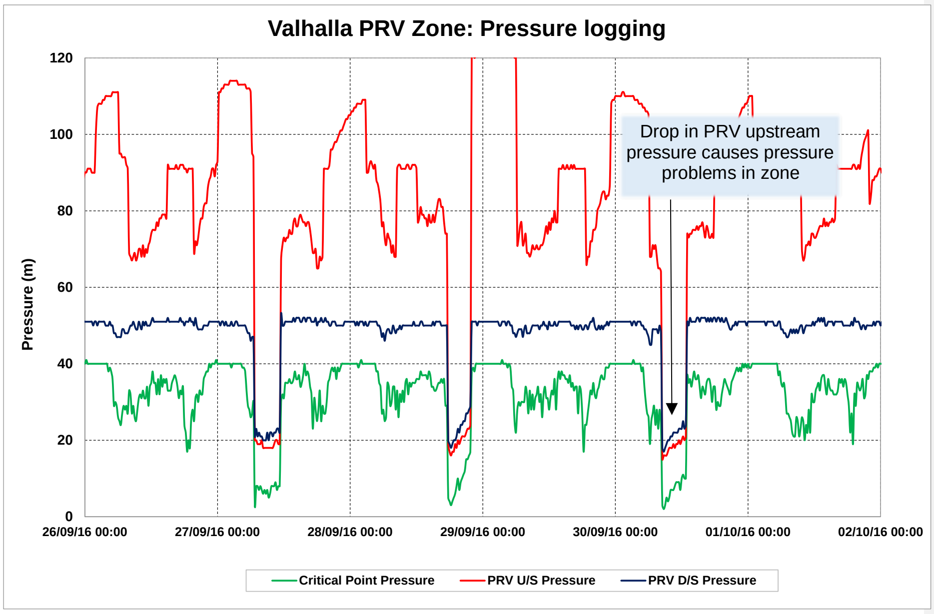


Figure 7: Pressure-logging graph: Valhalla PRV

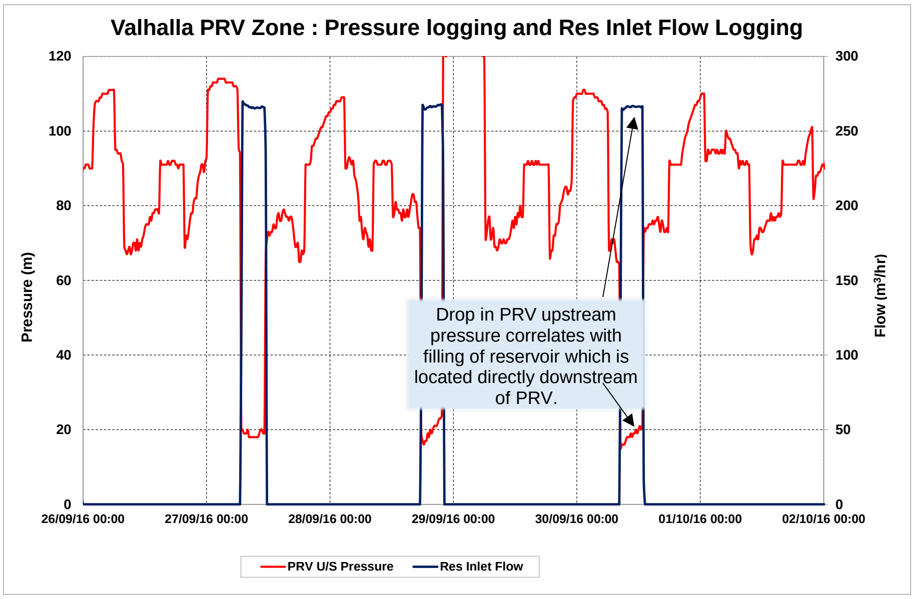


Figure 8: Pressure- and flow-logging graph: Valhalla PRV and Valhalla Reservoir inlet

3.2 Cross-boundary Connections

3.2.1 Background

Unauthorised opening of cross-boundary connections between water management zones is another common problem experienced in many water reticulation systems. Many water management zones have boundary connections with adjacent zones. These connections can be opened during an emergency or when repair work is undertaken in one of the zones. However, in many cases, these boundary connections are opened for other reasons or even unknowingly by operational staff. This causes water to flow from the zone with the higher pressure to the zone with the lower pressure. Cross-boundary flow can cause significant problems in both zones.

Some examples of cross-boundary flow include:

- If a boundary connection is opened between a tower zone and a reservoir zone, it normally results in water flowing from the tower zone to the reservoir zone. The pressure inside the reservoir zone increases, which may cause pipes to burst. In addition, reservoir outlets are not designed to close when the pressure head on the outlet of the reservoir is more than the reservoir top water level. Therefore, the higher pressure in the reservoir zone may also cause reservoir overflows.
- If a boundary connection is opened for a PRV zone, it causes water to flow in or out of the PRV zone through the boundary connection. The first graphic in Figure 9 shows the potential impact of an open boundary valve in a PRV zone. In the first example, the pressures inside the PRV zone increased since the supply into the zone was through the open boundary valve and not through the PRV. The second graphic in Figure 9 shows the normalised situation with the boundary valve closed, with the PRV supplying the zone.

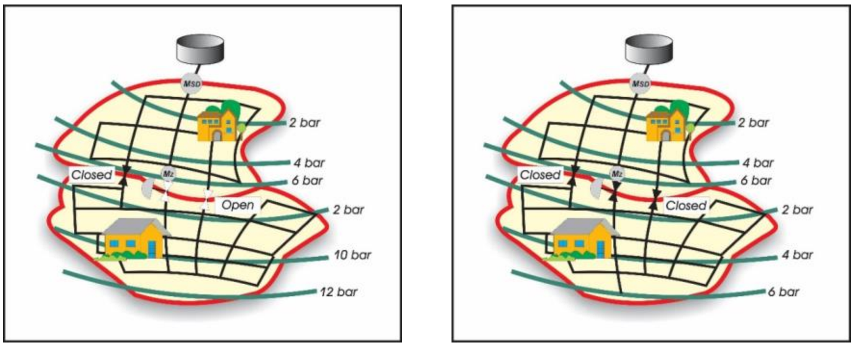


Figure 9: Potential impact of an open boundary valve for a PRV zone

It is not always obvious that there is a cross-boundary connection or that it has been opened and, in this regard, a systematic fault-finding approach is proposed to identify and solve such problems. The approach discussed in this section includes suggested steps to detect and resolve open cross-boundary connections between water management zones.

Due to the problems associated with unauthorised opening of cross-boundary connections, it is normally best to minimise the number of cross-boundary connections in a water reticulation network and to only keep the connections that will be critical during an emergency. One method (developed by the City of Tshwane) is to cap less important boundary connections and to install an above-ground hydrant on each side of the capped pipe, approximately 1 m apart. The above-ground hydrants provide a visual indication of the zone boundary. During an emergency, a flexible hose can be connected between the hydrants to provide additional supply. See Figure 10 for an example.

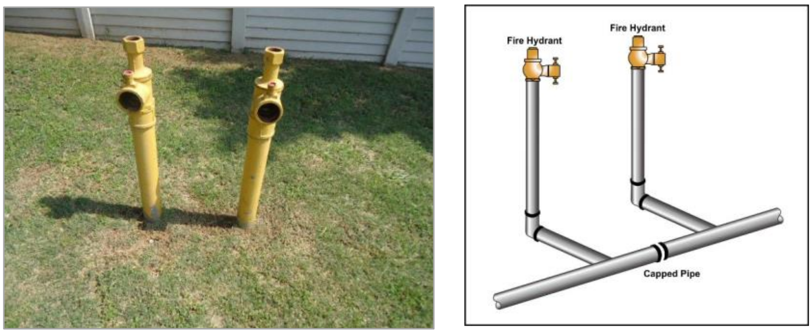


Figure 10: Double hydrant used to separate water management zones in the City of Tshwane

3.2.2 Approach

The tasks shown in Table 8 can be undertaken if it is suspected that there is a cross-boundary connection. It should be noted that operational personnel normally become aware of the symptoms of an open boundary valve (e.g. increase in burst pipes) before they realise that a boundary valve has been opened. The tasks in Table 8 are shown more or less in the order they can be undertaken; however, the order can be changed depending on the knowledge of the system or the specific situation.

Table 8: Fix cross-boundary connections

Task	Description
Check known boundary valves	If it is suspected that a boundary valve has been opened, the obvious first step is to check all boundary valves and confirm that they are closed. If some boundary valves do not seal properly, they should be replaced. If the problem is not resolved thereafter it could mean that there is an unknown boundary connection. The steps that follow can be undertaken to investigate the problem.
Log pressures and flows	The next step should be to install pressure loggers inside the zone with the suspected problem as well as in adjacent zones. If there are bulk meters on the inlet and outlet of the zone, it will also be useful to install flow loggers. The logging results should be evaluated to see if one or more of the following symptoms are observed: • Check if the logged pressure inside the zone is higher or lower than the expected pressure. The expected pressure can either be based on previous logging results or on the hydraulic model results. If the logged pressure is higher or lower than the expected pressure, it could mean that there is an open boundary connection. • Check if the pressure profile inside the zone is the same as in adjacent zones. If the pressure profile inside the zone increases and decreases at exactly the same times and with the same magnitude as in an adjacent zone, it could mean there is an open cross-boundary connection. • If the logged flow at the inlet(s) to the zone drops to zero at night, it could mean there is an open boundary connection. • Check the reservoir or tower overflow after confirming that the level control valve is operational and correctly set. If in the affirmative, it could mean there is an open boundary connection.
Do detailed checks	If the logging results point to a possible open boundary connection, the following tasks can be undertaken to locate the problem: • The number of hours per day during which the pressure inside the zone exceeds the theoretical pressure normally provides an indication of the size of the potential cross-boundary connection. If the pressure is affected only at night, it would suggest a small boundary connection. If the pressures are affected during the day and night it would suggest a large connection. • The pipe layout drawing should be inspected to see if there are obvious positions where cross-boundary connections could have been installed but not indicated on the drawing. These positions can typically be where the pipes from two adjacent zones are close to each other. The possible cross-boundary sites should be marked on a drawing. • The next step will be to plan and undertake pressure drop tests for pockets of the network to check if there are any unknown boundary connections in that pocket. The basic idea is to isolate a pocket of the network on one side of the boundary and confirm if the pressure drops to zero inside the pocket. If the pressure drops to zero it is confirmed that there are no unknown connections to that pocket and all the known boundary valves to the pocket close properly. • If the pressure inside a pocket does not drop to zero during a drop test, it will suggest that an unknown connection exists or that one or more of the known boundary valves do not close properly. In this case, the pocket used for the drop test should be split into smaller areas and the test should be repeated for each smaller area.

Task	Description
Do detailed checks (continued)	• Once it has been confirmed in which smaller area the problem occurs, further work should be undertaken to pinpoint the exact location of the cross-boundary connection. The pinpointing can be undertaken by either using equipment such as ground-penetrating radar or by simply excavating at the location of the suspected cross-boundary connection. Once a cross-boundary connection has been located, the pipe should be capped or a boundary valve should be installed. Terminology A drop test refers to the procedure of isolating a section/portion/ pocket of the water network and checking if the pressure drops to zero. If the pressure drops to zero, it is confirmed that there are no unknown connections to that section/portion/pocket and all the known boundary valves to the section/portion/pocket close properly.

3.2.3 Case Study 1: Albertville PRV Zone (Johannesburg)

The case study is from the Albertville pressure management zone in Johannesburg. A locality map of the area is shown in Figure 11. A PRV refurbishment project was undertaken in the area and flow and pressure loggers were installed at the PRV and meter. On a certain date, the flow through the PRV decreased to zero at night. This prompted further investigation.

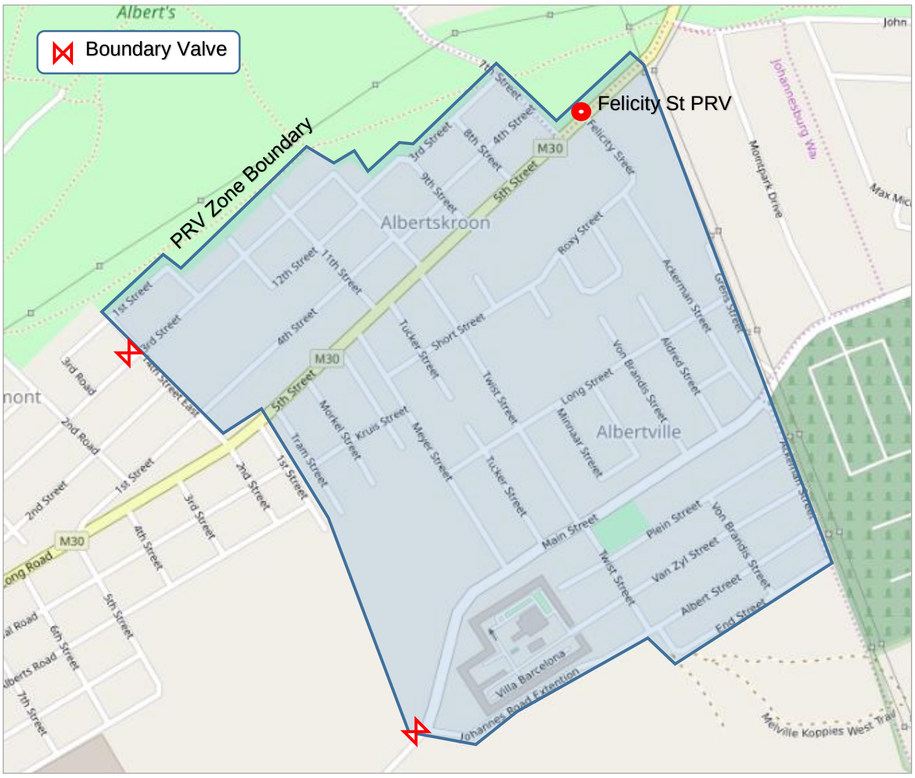


Figure 11: Locality map of Albertville PRV Zone

The approach followed to identify and solve the problem is shown in Table 9.

Table 9: Approach to fix cross-boundary connections in Albertville

Task	Outcome/Conclusion
Log pressures and flows	A PRV refurbishment project was undertaken in the area, and flow and pressure loggers were installed at the PRV and meter. During the first two days indicated on Figure 12, the zone operated with no apparent problem. On the third day, something changed and the flow dropped to zero in the evenings between 23:00 and 03:00. Furthermore, the PRV downstream pressure showed an increase over the same time period. This indicated that the PRV was closed in the evenings (zero flow) because it received a higher backpressure (pressure pushing back against the downstream end of the PRV). It was concluded that the backpressure originated from an opened boundary valve.
Check known boundary valves	All known boundary valves were subsequently checked and one boundary valve was found open. After the open boundary valve was closed, the pressures and flow at the PRV returned to normal.
Do detailed checks	The zone was confirmed discrete after the known boundary valves were inspected and, therefore, no further investigations were required.

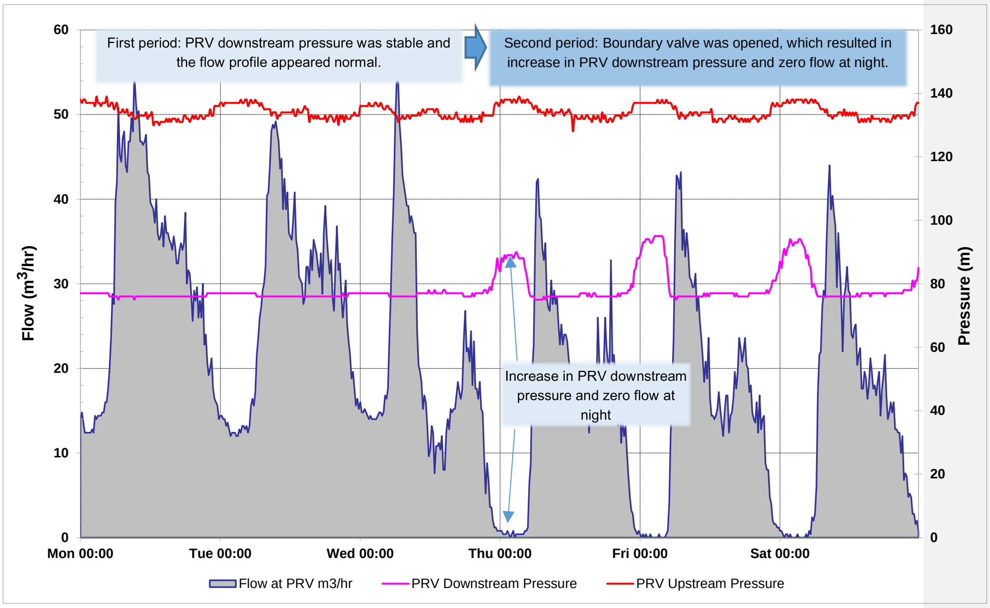


Figure 12: Pressure- and flow-logging graph: Albertville

3.3 Reservoir Overflow

3.3.1 Background

Reservoirs or towers that overflow is another common operational problem. Several factors can cause reservoir overflow, which include a faulty level control valve, incorrect setting of a level control valve, a faulty pump switch or even an open cross-boundary connection as described in the example below. Most of these problems can easily be identified through basic site inspections. Open cross-boundary connections can be investigated in the same manner as discussed in Section 3.2.

3.3.2 Approach

Reservoir overflow can be investigated using the approach discussed in Table 10.

Table 10: Fix reservoir overflow

Task	Description
Check reservoir level control valve	If the level control valve is not operational or not set correctly, it could result in reservoir overflow. The setting on the level control valve should be checked and adjusted if required. If the level control valve is not operational, it should be serviced and recommissioned.
Check pump level switch	If the reservoir/tower is supplied by a pump, the pump level switch should be inspected and serviced/replaced if faulty. If the pump does not switch off when the reservoir/tower is full, it will result in overflow.
Log pressures and flows to check for cross-boundary connections	In some cases, reservoir overflow may be caused by an open cross-boundary connection. This can happen when high pressure from an adjacent zone (e.g. tower zone) enters the reservoir zone through an open boundary connection, which causes backflow into the reservoir resulting in the reservoir spilling. The cross-boundary connection can be located using the same principles discussed previously in Section 3.2.

3.3.3 Case Study 1: Blairgowrie Reservoir Zone (Johannesburg)

The case study is from the Blairgowrie Reservoir zone in Johannesburg. A locality map is shown in Figure 13. Since the reservoir supply area is very large, only the relevant portion of the zone is shown on the map. For several years, the Blairgowrie Reservoir overflowed at ad hoc periods. It was suspected that an open cross-boundary connection with the Linden reservoir zone was causing the problem.

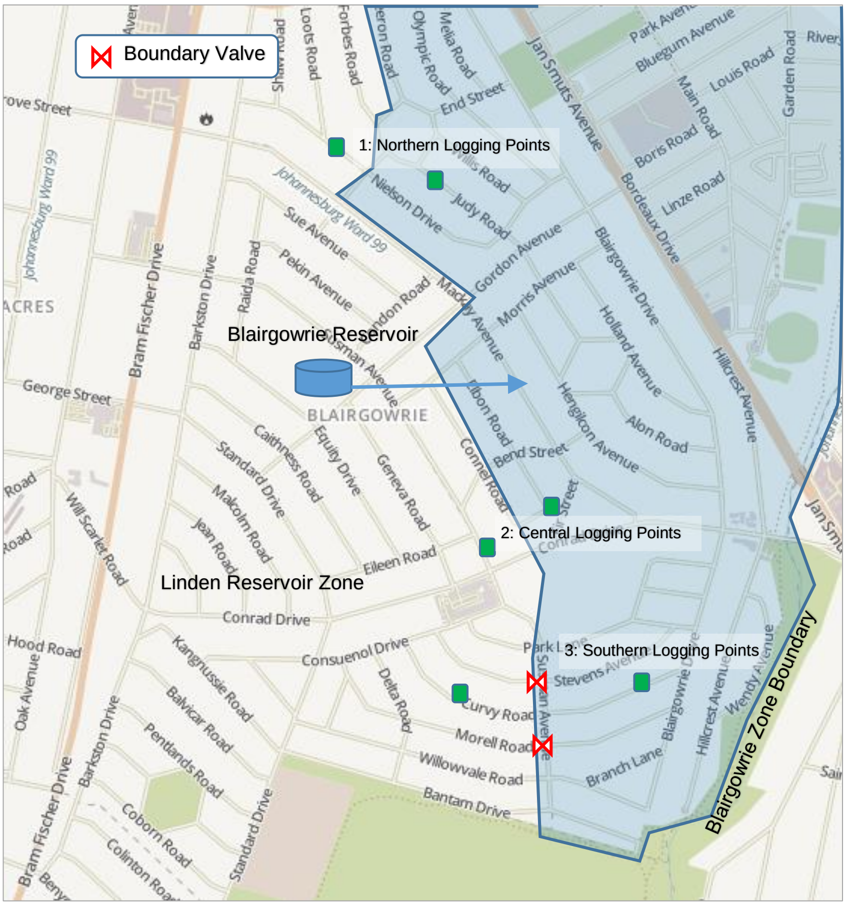


Figure 13: Locality map of Blairgowrie Reservoir Zone

The approach followed to identify and solve the problem is shown in Table 11.

Table 11: Approach to fix reservoir overflow in Blairgowrie

Task	Outcome/Conclusion
Check known boundary valves	The municipality suspected that the reservoir overflow problem was caused by an open boundary connection. Therefore, all known boundary valves were checked as a first step. All boundary valves were found closed, however, it was noted that the boundary valves were not marked/painted on-site. There was some confusion on-site as to which valves were supposed to be closed.
Log pressures and flows	Pressure loggers were subsequently installed at six locations on opposing sides of the Blairgowrie/Linden boundary (logging positions shown on locality map). The meter on the outlet of the Blairgowrie Reservoir was not operational, otherwise it would have been useful to install a flow logger on the meter to detect if there was reverse flow. Pressure-logging results are shown in Figure 14. **Northern logging points**: The pressures in Loots St and Forbes St on opposing sides of the Blairgowrie/Linden boundary were significantly different. It was deduced that the potential open boundary connection was not located in this area. **Central logging points:** The pressures in Gordon St and Elbon St on opposing sides of the Blairgowrie/Linden boundary were significantly different. It was deduced that the potential open boundary connection was not located in this area. **Southern logging points:** The pressures in Curvey St West and Curvey St East had a similar profile and the pressure did not differ significantly as expected and as predicted by the hydraulic model. It was deduced that a cross-boundary connection existed in this area.
Do detailed checks	The boundary valve in Curvy St, which previously was thought to be closed, was revisited. It was established that the wrong valve was closed. The correct valve was subsequently closed and the pressures at the southern logging points in Curvey St changed to the expected pressure (see Figure 14). The reservoir overflow problem was immediately resolved once the correct boundary valve was closed. A proposal was made to install the double hydrant system at the Curvey St boundary valve (as used by City of Tshwane) to prevent accidental opening of this boundary valve in future.

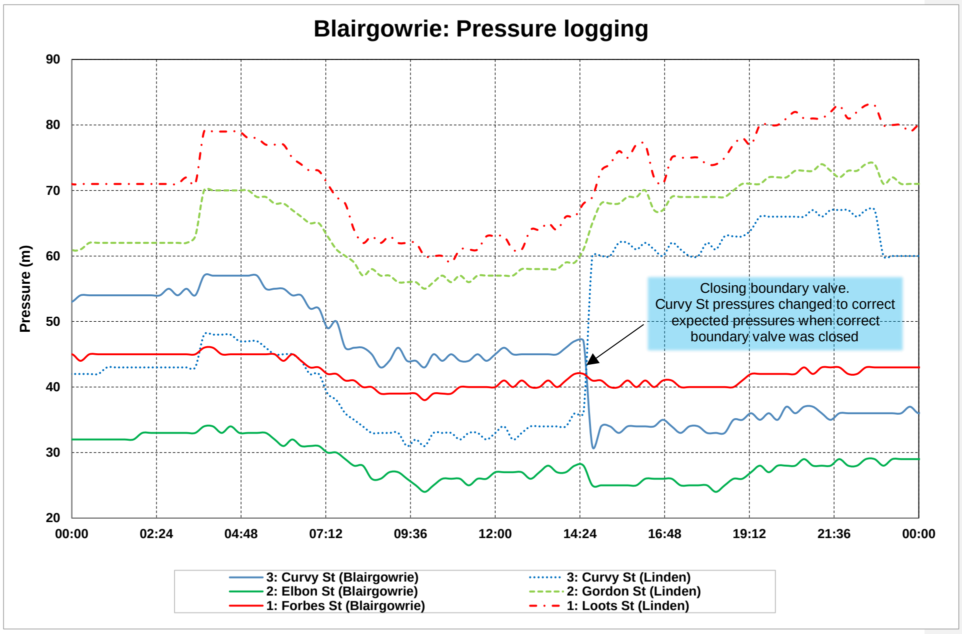


Figure 14: Pressure-logging graph: Blairgowrie

3.4 Blocked Strainer

3.4.1 Background

Strainers are used to collect debris in water mains and protect water infrastructure such as meters and PRVs. A strainer consists of an outer shell and an inner basket, which is typically manufactured from perforated stainless-steel plate. Strainers should be inspected and cleaned as part of a planned maintenance programme. Failure to do so may lead to blockages, which can cause significant low-pressure problems in a water network. It can be difficult and time-consuming to open large strainers. Therefore, it is sometimes useful to check the pressure difference over the strainer before deciding to open and clean a strainer.

3.4.2 Approach

The simple approach discussed in Table 12 can be followed to check if a strainer is blocked.

Table 12: Check if a strainer is blocked

Task	Description
Check/log pressure on inlet and outlet of strainer	The approach simply involves checking or logging the pressure on the inlet and outlet of a strainer to see if there is a pressure difference. The higher the pressure difference over the strainer, the more debris have likely been collected inside the strainer. Some strainers are supplied with pressure tappings on the inlet and outlet that can be used to check the pressure. If such tappings are not available on the strainer, the pressure can be checked at any available point upstream and downstream of the strainer.
If necessary, open and clean strainer	If the pressure difference is significant over a strainer, the strainer should be opened and cleaned. If the pressure difference over the strainer remains significant even after cleaning, then a new strainer basket with a larger open area will be required. The total open area refers to the sum of the areas of all the openings in the strainer basket. A larger open area may be achieved with larger openings or through the redesign of the basket, which will allow for a larger surface area of the basket to decrease the pressure drop across

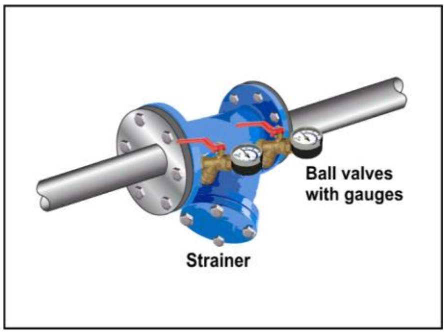


Figure 15: Example of a strainer with pressure tappings on the inlet and outlet (left) and strainer basket filled with debris (right)

3.4.3 Case Study 1: Protea Glen PRV (Johannesburg)

The case study is from the Protea Glen area in Johannesburg. The zone is supplied from a direct Rand Water connection with a PRV (see locality map in Figure 16). The PRV was earmarked for servicing and recommissioning; however, low pressures were experienced upstream of the PRV. As a result, pressure and flow loggers were installed to investigate the cause of the problem.

Figure 16: Locality map of Protea Glen

The approach followed to identify and solve the problem is shown in Table 13.

Table 13: Approach to clean a blocked strainer in Protea Glen

Task	Outcome/Conclusion
Check/log pressure on inlet and outlet of strainer	Pressure loggers were installed on the PRV upstream, PRV downstream and the critical point. A flow logger was installed on the Rand Water meter. There was no strainer inside the PRV chamber. The initial logging data showed that the PRV upstream and PRV downstream pressures were identical. Therefore, the PRV was fully open. The PRV upstream pressure reduced significantly during the day to an extent that it was not possible to set the PRV at this stage. Due to the low pressure at the PRV, the pressure at the critical point was also very low during the day. At night, the PRV upstream pressure increased significantly (see Figure 17). There was not a pressure-logging point at the Rand Water meter; however, based on logging information obtained elsewhere on this Rand Water line, it was established that the pressure in the Rand Water line did not fluctuate to the same extent as the Protea Glen PRV upstream pressure. It was concluded that a restriction between the Rand Water meter and the PRV caused the reduction in pressure. Further site investigations revealed that there was in fact a strainer in a separate chamber upstream of the PRV, which was not located during the initial site visit.

Task	Outcome/Conclusion
If necessary, open and clean strainer	The strainer was cleaned, and this resulted in a large increase in upstream pressure at the PRV to the extent that the PRV could be set. Setting of the PRV also resulted in lowering of the MNF (see Figure 17). The pressure at the critical point improved slightly during the day as a result of the higher pressure at the PRV. If there were tappings to check pressure on the upstream and downstream of the strainer (and it was known that there was a strainer), the cause of the low-pressure problem could have been located much faster.

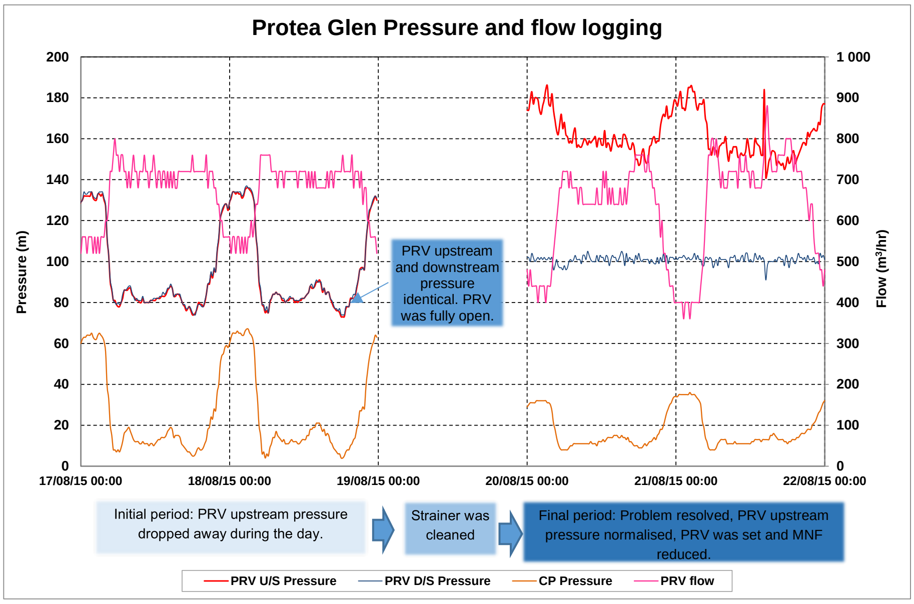


Figure 17: Pressure- and flow-logging graph: Protea Glen

3.5 Erratic Pressure

3.5.1 Background

Erratic/fluctuating pressures in a water reticulation network can cause damage to the network and have a negative impact on consumers. Several operational problems can cause or contribute to erratic pressures. Some of the most common problems are discussed in this section.

3.5.2 Approach

The approach discussed involves logging pressures in the network, identifying the cause of the erratic/fluctuating pressures and recommending actions to resolve the problem.

Table 14: Fix erratic pressures

Task	Description
Log pressure and flow	If erratic/fluctuating pressures are expected/experienced in a water management zone, pressure and flow logging should be undertaken at a few points in the zone. These logging points can include (but are not limited to) the following: • Bulk inlet and outlet points. • PRVs on zone inlets/outlets. • Pump stations. • Supply pipes to tanks/reservoirs. • Supply points to large consumers.
Identify cause of erratic pressure	The logging results should be evaluated to see if pressures are stable or erratic. If pressures are erratic, further investigation should be undertaken to identify the cause thereof. The erratic pressures could be caused by any of the following: • Erratic outlet pressure from a PRV or pump (significant fluctuation in pressure). • Erratic demand profile at a large consumer in the zone (e.g. sudden spikes in flow caused by filling of a tank at a consumer). • Sudden opening/closing of the inlet to a reservoir/tank.

Once the cause of the erratic pressures has been identified, the remedial actions in Table 15 can be proposed.

Table 15: Remedial actions to fix erratic pressure

Type	Action
Erratic demand profile at large consumer	If a large consumer has an erratic demand profile, it could cause pressure fluctuation in the zone. This can typically occur when a storage tank at the consumer is suddenly filled. In such cases, the water supplier should discuss remedial action options with the consumer. If the problem is caused by the sudden filling of a tank, it could be proposed that the maximum flow rate on the connection is restricted with an orifice plate or control valve. The lower flow rate will then result in longer filling times for the tank and less fluctuation in pressure. If the problem is caused by a large consumer process that draws water directly from the network, it could be proposed that an on-site storage tank is installed and that the maximum inlet flow to the tank is limited.
Erratic outlet pressure at PRV	Some of the causes of erratic outlet pressures at PRVs are: **Oversized PRV** If a PRV is oversized (too large), it could be difficult to get the PRV sufficiently stable. The following remedial action may be considered: • A smaller PRV can be installed. • A low-flow handling device can be installed inside the PRV that will assist the valve to handle the low flow better. Most PRV suppliers have such devices available (e.g. Low-Flow System for Cla-Val (LFS) or V-port for Bermad). • It could also be considered to install a low-flow bypass PRV in parallel with the main PRV. The bypass PRV is then set slightly higher (typically 5 m) than the main PRV.

Type	Action
Erratic outlet pressure at PRV (continued)	**Incorrectly sized restriction tube fitting** A restriction tube fitting is used as a key component in the hydraulic control circuit for a PRV (refer to Figure 18). Some suppliers use a needle valve in place of the restriction tube fitting. The same principles as discussed below will then apply. If the restriction tube fitting is incorrectly sized, the PRV outlet pressure could be unstable. PRV manufacturers specify the size of restriction fitting to use with different size PRVs. The ratio of PRV upstream pressure versus the PRV downstream pressure, as well as the flow through the PRV may, however, also impact on the ideal restriction fitting size. If it is suspected that the restriction fitting is incorrectly sized, the first step would be to consult the manufacturer's guidelines. If the restriction fitting size recommended by the supplier does not result in a sufficiently stable PRV, then different size restriction fittings (smaller and larger) can be tried until the PRV outlet pressure is sufficiently stable. **Internal PRV wear or damage** Internal wear inside the PRV could also cause the PRV to behave erratically. If the PRV is correctly sized and it was confirmed that the restriction tube fitting is correct, the PRV should be serviced. A full service involves dismantling all PRV parts, cleaning all parts and replacing defective parts. Care should be taken to ensure that the stem/shaft of the PRV is polished. If the PRV body has severe internal damage, it may be better to replace the PRV.
Erratic pump outlet pressure	If the pump outlet pressure is erratic, further investigation should be undertaken to establish what causes the problem. If more than one pump is pumping simultaneously, each pump should be inspected to ensure that their duty points are the same. If required, the pumps should be serviced and the impellers checked. Damaged impellers should be replaced. Non-return valves or pump control valves should be inspected to ensure that they are operational and that there is no reverse flow through these valves when a specific pump is not running.
Sudden opening/closing of a tank or reservoir	Sudden closing of a reservoir or tank will cause water hammer in the network upstream of the reservoir/tank. The following can be considered to limit the impact on the network: • A hydraulic level control valve can be installed on the inlet of the tank and the level control valve can be fitted with closing speed control. • The level control valve should be set to allow for some fluctuation of the water level (typically varying between 70% and 95% of the top water level) to avoid opening of the level control valve every time the water level drops slightly. • The level control valve can be fitted with a rate-of-flow function to limit the maximum flow rate at which the tank/reservoir can fill. This will prevent quick opening/closing cycles of the inlet to the tank/reservoir.

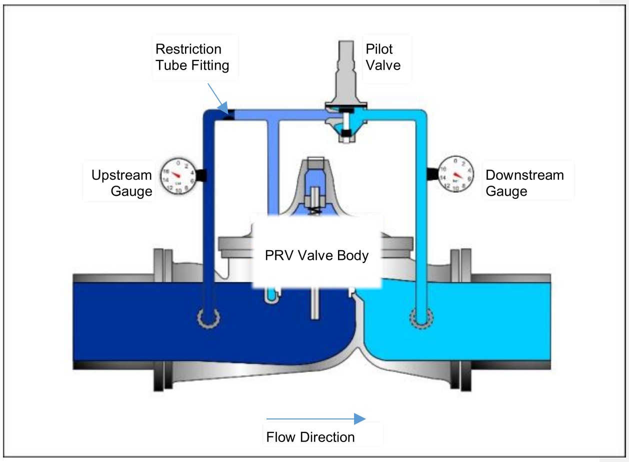


Figure 18: Examples of restriction tube fittings (left) and a schematic layout of the standard hydraulic control circuit on a PRV (right)

3.5.3 Case Study 1: Marlboro (Johannesburg)

The case study is from the Ninth St PRV zone in the Marlboro area in Johannesburg. The Ninth St PRV (150 mm diameter) was oversized due to higher fire-flow requirements for the industrial area that it supplied. The PRV outlet pressure was erratic, which caused a similar erratic pressure profile throughout the zone.

The approach followed to identify and solve the problem is given in Table 16.

Table 16: Approach to fix erratic pressure in Marlboro

Task	Outcome/Conclusion
Log pressures and flows and identify the cause of the erratic pressure	The pressures and flows in the Ninth St PRV zone were logged. The PRV outlet pressure was erratic, which caused a similar erratic pressure profile throughout the zone (see Figure 19). There were no tanks or pumps in the zone. There were no large consumers in the zone that could have impacted on the pressures in the zone. It was therefore concluded that the only cause for the erratic pressures could have been the PRV.
Modify PRV	The sizing of the Ninth Rd PRV (150 mm diameter) was checked and it was found that the PRV was oversized. The PRV was oversized due to the higher fire risk for industrial consumers in the zone. A low-flow handling device was subsequently fitted inside the PRV, which improved the stability of the PRV drastically (see last day of logging results in Figure 19).

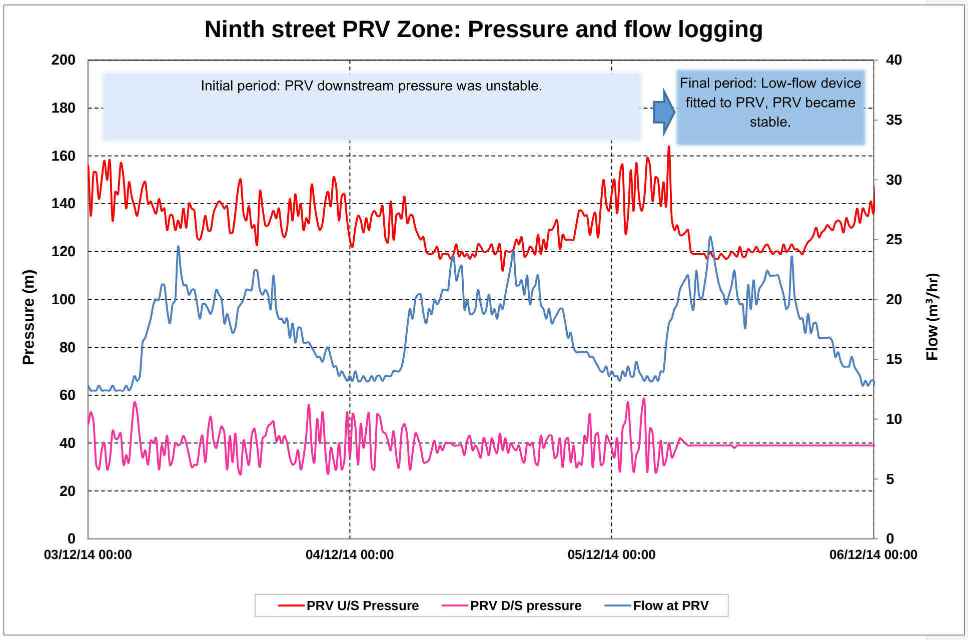


Figure 19: Pressure- and flow-logging graph: Ninth St PRV in Marlboro

3.5.4 Case Study 2: Sterrezicht (Vredenburg)

The case study is from the Sterrezicht area in Vredenburg in the Western Cape. General pressure and flow logging was undertaken in the Sterrezicht zone to determine the leakage levels and to verify if the zone was discrete or not. Significant fluctuation in pressure was observed throughout the zone, which prompted further investigation.

Figure 20: Locality map of Sterrezicht

The approach followed to identify and solve the problem is given in Table 17.

Table 17: Approach to fix erratic pressures in Sterrezicht

Task	Outcome/Conclusion
Log pressures and flows	General pressure and flow logging was undertaken in the Sterrezicht zone to determine the leakage levels and to verify if the zone was discrete or not. Significant pressure fluctuations were observed throughout the zone (Figure 21).
Refurbish pumps and replace non-return valves at pumps	There were no PRVs, no large consumers and no reservoirs/tanks in the zone. It was concluded that the pump supplying the zone was the only potential cause for the erratic pressures. It was also established that the pressures were especially erratic when a jockey pump worked simultaneously with one of the main pumps. The pumps were subsequently serviced and the non-return valves at each pump were replaced. The logging results one year later (in Figure 22) show that the pumps delivered a constant outlet pressure after being serviced.

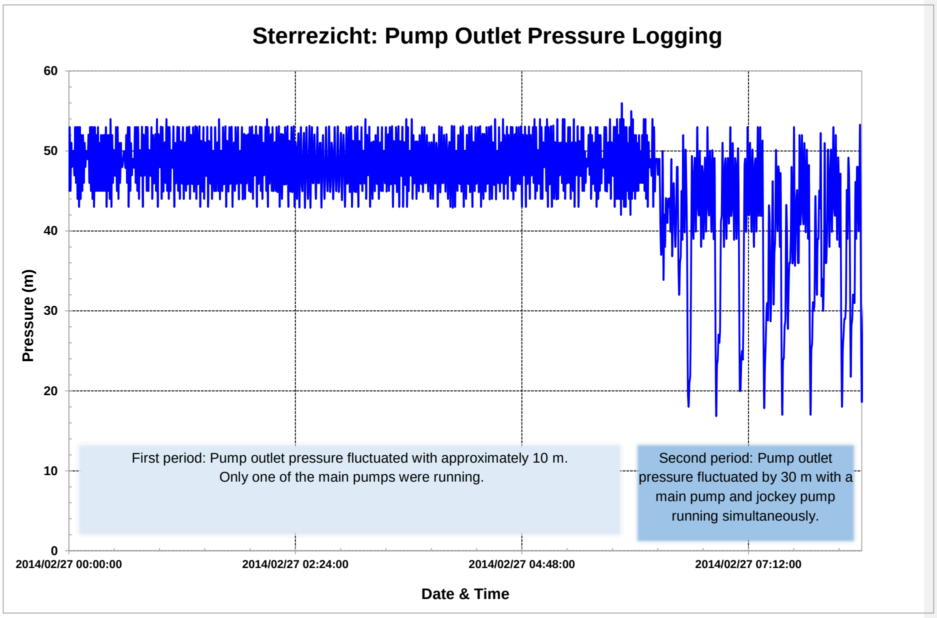


Figure 21: Pressure- and flow-logging graph before problem was resolved: Sterrezicht

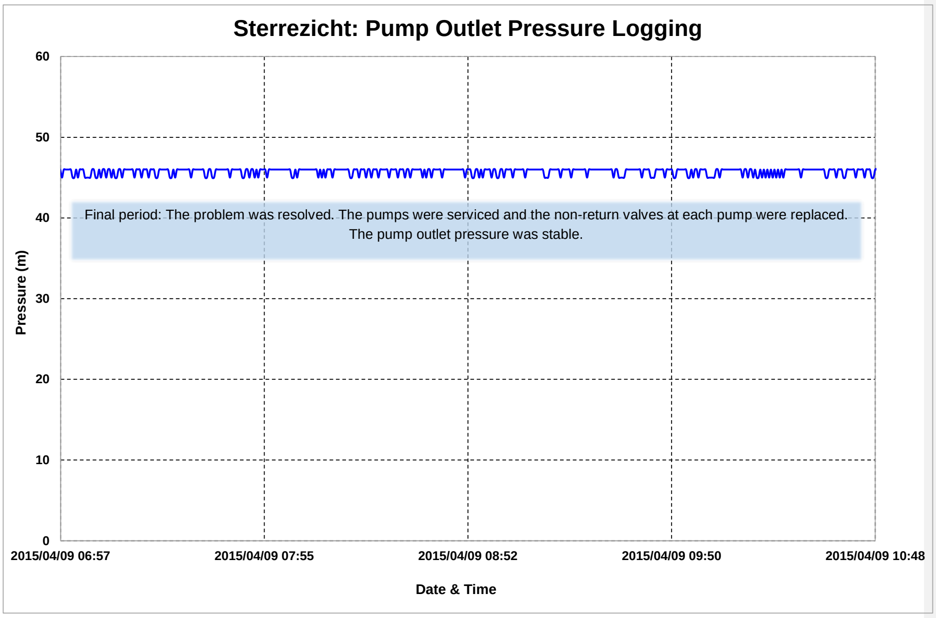


Figure 22: Pressure- and flow-logging graph after problem was resolved: Sterrezicht

3.5.5 Case Study 3: Saldanha Bay

The case study is from Saldanha Bay in the Western Cape. General pressure and flow logging was undertaken on the bulk supply line to Saldanha Bay to determine the extent of leakage as well as determine water use patterns of large consumers on the line. Significant fluctuation in pressure was observed on the bulk supply line, which prompted further investigation.

Figure 23: Locality map of Saldanha Bay bulk supply line

The approach given in Table 18 was followed.

Table 18: Approach to fix erratic pressures in Saldanha

Task	Outcome/Conclusion
Log pressures and flows	Pressure- and flow-logging data was already available from the investigation undertaken on the bulk supply line. Significant fluctuation in pressure was observed on the bulk supply line, which prompted further investigation. There was no pump on the bulk line. It was found that none of the large consumers on the line had a significant impact on the pressures. The bulk line supplied the Klein and Kalkrug Reservoirs in Saldanha Bay from where the remainder of the town was supplied. The pressure fluctuation on the bulk main did not correlate with the filling times of the Kalkrug Reservoir, but it did correlate with the filling times of the Klein Reservoir (see Figure 24 and Figure 25). It was concluded that the regular and sudden opening and closing of the inlet to the Klein Reservoir was creating the fluctuation in pressure in the bulk line.
Implement remedial action	A recommendation was made to improve the level control at the Klein Reservoir to avoid regular and sudden opening and closing of the inlet and to possibly limit the maximum flow rate, which would allow for longer reservoir filling times, which would cause less fluctuation in pressure.

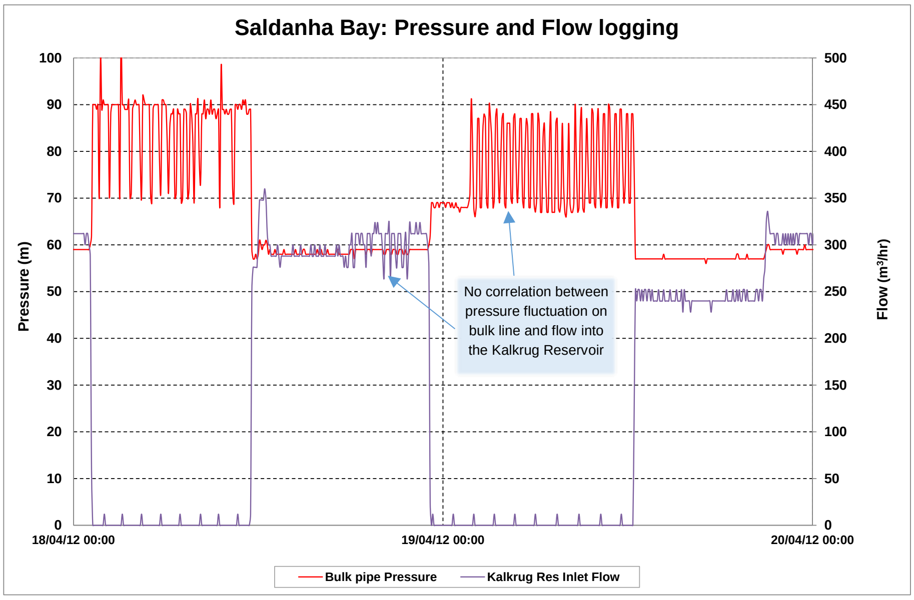


Figure 24: Pressure- and flow-logging graph at Kalkrug Reservoir: Saldanha Bay

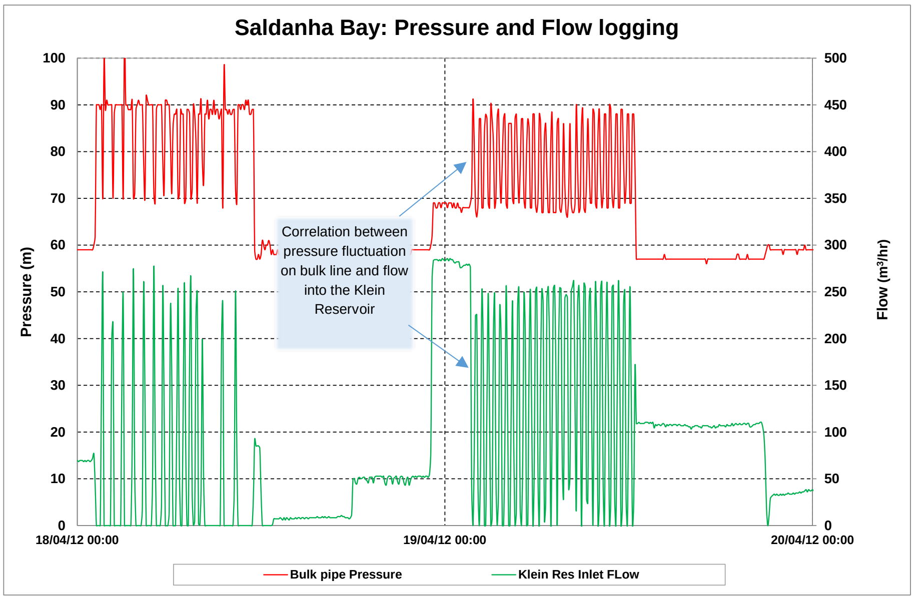


Figure 25: Pressure- and flow-logging graph at Klein Reservoir: Saldanha Bay

3.6 Suspected Consumer Leakage

3.6.1 Background

When consumers receive a large water bill, they often complain/suggest that the problem was caused by an inaccurate water meter. In some cases, the consumer meter could be faulty and the municipality may arrange to do a meter test. However, in other cases, the high consumption recorded on the meter could be a result of leakage at the consumer's property. Municipal staff need to be able to establish whether leakage at the consumer may have contributed to the high water bill or not.

3.6.2 Approach

The approach involves logging the flows at consumer meters to check if there is leakage and to quantify if the leakage is low, medium or high. It is recommended to log for a period of seven days to ensure sufficient information is available. If a consumer has more than one water meter, the flow should be logged at all meters and a graph should be prepared for the combined flow rate through all the meters.

Table 19: Establish if there is suspected consumer leakage

Task	Description
Log flow	The first step will be to do flow logging at all the meters supplying a consumer.
Calculate the cost of leakage	The MNF for a consumer can be used to calculate the cost of leakage. This will indicate what percentage of the water bill can be contributed to leakage.
Evaluate minimum flow over average flow	A general rule that can be used to gauge the extent of leakage is to check the ratio of minimum flow over the average flow. The lower this ratio, the lower the degree of leakage; the higher the ratio, the higher the degree of leakage. The following rough guideline can be used: • Minimum/average ≤ 15% low leakage levels. • Minimum/average > 15%, ≤ 30% medium leakage levels. • Minimum/average > 30%, ≤ 60% high leakage levels. • Minimum/average > 60% very high leakage levels.
Determine actual minimum flow for large industrial consumers	For most consumers, it is easy to determine the minimum flow from the seven-day logging graph. It could be difficult to establish the minimum flow for large industrial consumers that use water at night. Logging at such industrial consumers may have to be planned over a period where the processes at the plant are shut down for maintenance.
Analyse MNF for residential complexes	For residential complexes, it is possible to prepare a night flow analysis using the same principles as for a municipal water management zone as discussed in the Sanflow User Guide (McKenzie, 1999).

3.6.3 Case Study 1: Residential complex (City of Tshwane)

The case study is from a residential complex in the City of Tshwane municipality. The consumer lodged a complaint with the City of Tshwane regarding their high water bill, which they claimed was caused by an inaccurate water meter.

The approach given in Table 20 was followed.

Table 20: Approach to establish suspected consumer leakage at a residential complex in City of Tshwane

Task	Outcome/Conclusion
Log flows and analyse logging data	The City of Tshwane installed a temporary flow logger at the consumer meter. By evaluating the logging data, it was established that there was a significant night flow and that the ratio of MNF/average flow was high at 60% (Figure 26). It was concluded that leakage was the main cause for the high water bill of the consumer. The consumer was informed by the City of Tshwane of the leakage problem and was requested to locate and repair the leak.

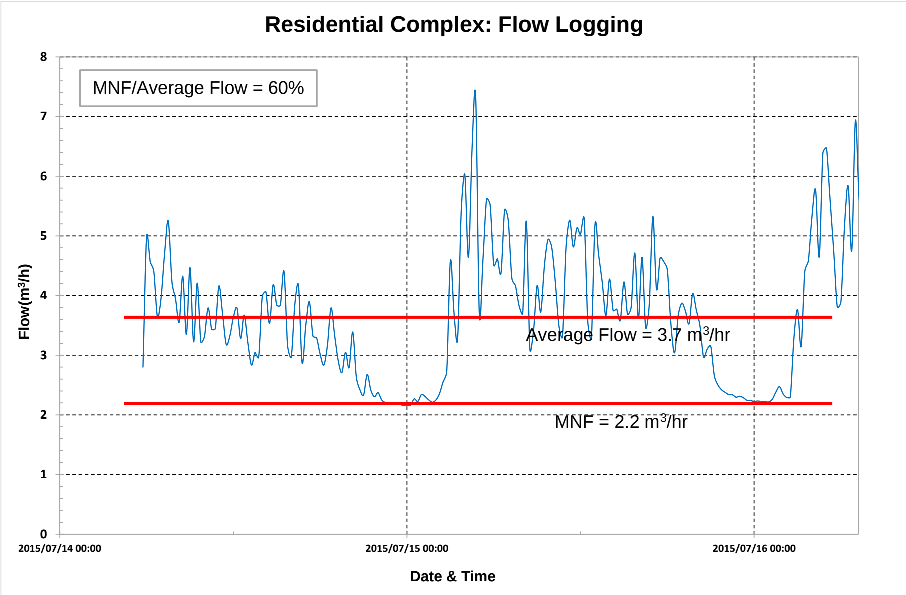


Figure 26: Flow-logging graph: Residential complex (City of Tshwane)

3.6.4 Case Study 2: School (City of Ekurhuleni)

The case study is from a school in the City of Ekurhuleni municipality. The school had a permanent flow logger on their water meter and the data was relayed to a web-based monitoring system. The web-based monitoring system triggered an alarm when the MNF increased above the norm.

The approach in Table 21 was followed.

Table 21: Approach to establish suspected consumer leakage at a school in City of Ekurhuleni

Task	Outcome/Conclusion
Log flows and analyse logging data	By evaluating the logging data, it was established that the MNF for the school had been increasing over a period of a few weeks (see Figure 27). There was no legitimate night usage at the school and it was clear that the increasing MNF was due to a leak that was growing in volume.
Repair leak	Field inspections revealed that the leak was on the irrigation system of the school. The leak was subsequently repaired and the night flow reduced to an acceptable level.

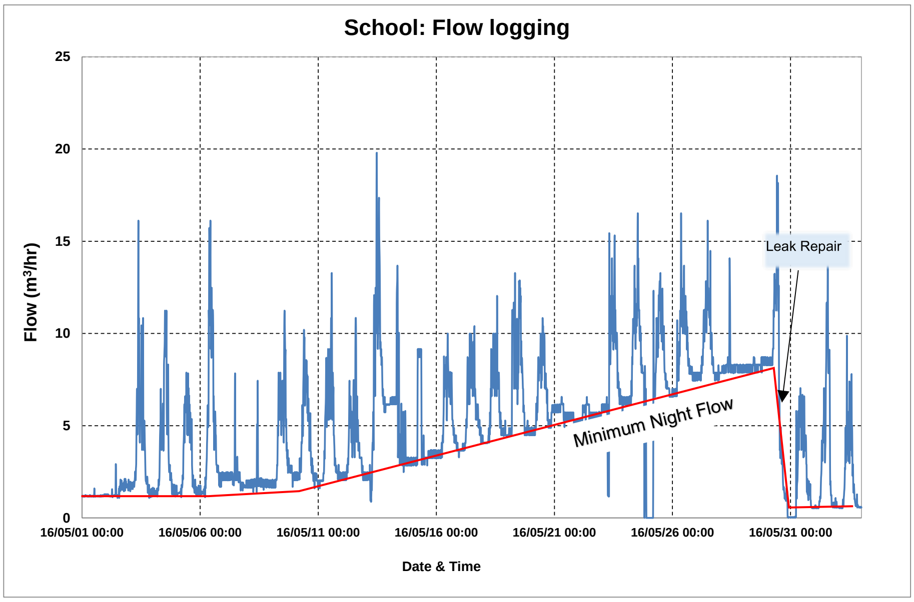


Figure 27: Flow-logging graph: School (City of Ekurhuleni)

3.6.5 Case Study 3: Industrial consumer (City of Tshwane)

The case study is from an industrial consumer in the City of Tshwane municipality. The City of Tshwane installed a permanent logger at this consumer to monitor their water usage. The logging data was relayed to a web-based monitoring system.

The approach in Table 22 was followed.

Table 22: Approach to establish suspected consumer leakage at an industrial consumer in City of Tshwane

Task	Outcome/Conclusion
Log flows and analyse logging data	The industrial consumer operates 24 hours a day, seven days a week. It was initially not clear which component of the night flow was due to leakage. However, every few months, the factory stopped operation for 24 hours. The night flows in these periods were used to determine the level of leakage. November 2015 was one such period where the factory's operations stopped for 24 hours. The night flow was high at 10 kl/hr and the consumer was informed to locate and repair the leakage (see Figure 28). In September 2016, the factory again stopped operations for 24 hours. It was noted that the night flow increased to 14 kl/hr (see Figure 29). It was clear that the consumer did not locate and repair the leakage in 2015 and that the night flow steadily increased over time. The consumer then received a written instruction from the City of Tshwane to locate and repair the leakage.

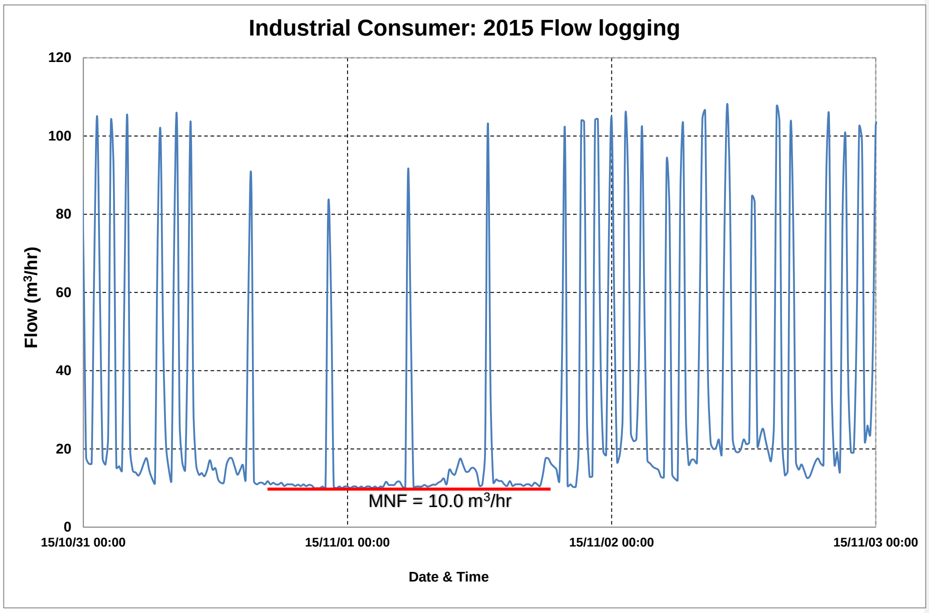


Figure 28: Flow-logging graph for 2015: Industrial consumer (City of Tshwane)

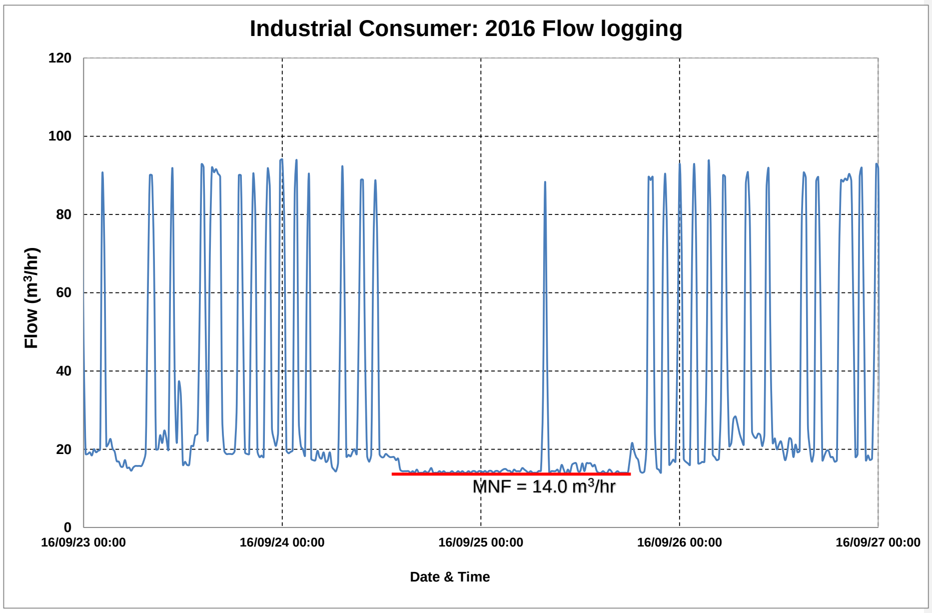


Figure 29: Flow-logging graph for 2016: Industrial consumer (City of Tshwane)

4 INVESTIGATION SUMMARY GUIDELINE

The following summary guideline can be used to plan the investigation and remedial action to resolve some of the common operational problems in water networks. It is recommended that pressure and flow logging, as well as the analysis of those logging results, should form an integral part of such investigations as this would assist in resolving operational problems quickly and efficiently.

Table 23: Low-pressure investigation guideline (for areas where pressure is normally acceptable)

Location	Possible Cause	Possible Remedy
Water network	Burst pipe.	Locate and repair burst pipe.
	Open boundary connection.	Check boundary connections and close open boundary connection.
	Closed network valves.	Locate and open closed network valves.
	Other restrictions in the network.	Identify and remove restrictions in the network by undertaking pressure checks between inlet of zone and the low-pressure complaint area.
	Differences between water network on-site and network shown on drawings.	Identify where water network on-site differs from the drawings by excavations and pressure checks. Correct water network where required (e.g. install missing connections between pipes, install missing pipe sections).
Consumer meter	Blocked consumer meter or blocked consumer strainer.	Check meters and strainers and clean consumer meter and/or consumer strainer if required.
Large consumer draw-off	Large consumer draw-off affects pressure in network.	Identify which large consumers have high draw-off by logging pressures and flows. Where applicable, recommend the installation of an orifice plate or control valve on the large consumer connection to restrict draw-off. In such cases, the large consumer may also be requested to install on-site storage tanks.
PRV suppling zone	PRV downstream pressure is not sufficient while the PRV upstream pressure is sufficient:	
	• PRV has no apparent problem but setting is too low.	Adjust PRV setting.
	• Blockage inside PRV.	Open PRV and remove blockage.
	• Malfunctioning PRV.	Consult PRV manufacturer guidelines for servicing and recommissioning of PRVs.
	PRV upstream pressure insufficient and lower than normal:	
	• Strainer upstream of PRV is blocked.	Clean strainer.
	• Pressure from bulk water supplier is lower than normal.	Consult with bulk water supplier to identify why the supply pressure is lower than normal and how the problem can be resolved.
	• Burst pipe on supply line.	Locate and repair burst pipe.
	• Abnormal high draw-off from line upstream of PRV.	Lower abnormal draw-off from line upstream of PRV, which may include restricting draw-off from large consumers or restricting draw-off to reservoirs upstream of PRV.
Reservoir/ tower	Insufficient storage in reservoir/ tower.	Create sufficient storage in the reservoir/tower.
Bulk water supplier connection	Insufficient pressure from bulk water supplier.	Consult with bulk water supplier to identify why the supply pressure is lower than normal and how the problem can be resolved.

Table 24: Open cross-boundary connection guideline

Location	Possible Cause	Possible Remedy
Zone boundary	Open boundary valve.	Check and ensure that all known boundary valves are closed.
	Unknown open boundary connection.	If an unknown open boundary connection is suspected, pressure logging inside the zone and in adjacent zones can be undertaken. The pressure profiles should be compared to establish if the pressure profiles inside the zone correspond with the pressure profiles in adjacent zones. This may point to a cross-boundary connection. Log flows if a meter is available at the zone inlet. If the flow at the zone inlet drops to zero at any point during the day, a cross-boundary connection most likely exists. Pressure drop tests can be undertaken by isolating small areas of the network near the zone boundary. If one or more of these small areas cannot be isolated with the valves shown on the drawing, it is possible that an unknown connection exists. Refer to case studies discussed in this document to locate exact position of cross-boundary connection.

Table 25: High-pressure investigation guideline (for areas where pressure is normally acceptable)

Location	Possible Cause	Possible Remedy
PRV supplying zone	PRV downstream pressure higher than normal:	
	• PRV has no apparent problem but setting is too high.	Adjust PRV setting.
	• PRV malfunctions and outlet pressure cannot be reduced.	Consult PRV manufacturer guidelines for servicing and recommissioning PRVs.
Zone boundary	Open boundary valve.	Check and ensure that all known boundary valves are closed.

Table 26: Erratic pressure investigation guideline

Location	Possible Cause	Possible Remedy
PRV supplying into zone or supplying downstream zones	PRV outlet pressure is erratic, which may be caused by the factors listed below:	
	• Oversized PRV.	• Replace PRV with smaller PRV. • Fit low-flow handling device inside PRV. • Install smaller bypass PRV in parallel with main PRV.
	• Incorrect restriction tube fitting for PRV/needle valve setting.	Try different size restriction fittings/needle valve settings until PRV is stable.
	• Wear and tear of PRV.	Service PRV, dismantle and clean all parts, and replace defective parts.
	• Obstruction inside PRV.	Service PRV and remove obstruction.
Pump	Pump outlet pressure is erratic.	Service pump, pump control valves and non-return valves at pumps.

Location	Possible Cause	Possible Remedy
Erratic draw-off from large consumer	If a large consumer has erratic draw-off, it could affect the pressures throughout the zone.	Identify which large consumers have high erratic draw-off by logging pressures and flows. Where applicable, recommend the installation of an orifice plate or control valve on the large consumer connection to restrict draw-off. In such cases, the large consumer may also be requested to install on-site storage tanks.
Erratic opening/ closing of level control valve	If a reservoir, tower or tank is supplied through a zone, the erratic opening and closing of the reservoir level control valve can influence the pressures throughout the zone.	Improve control functionality at level control valve to allow for some fluctuation of the reservoir level before the level control valve opens. If necessary, limit the maximum flow rate through the valve.

Table 27: Reservoir overflow guideline

Location	Possible Cause	Possible Remedy
Reservoir	Reservoir level control valve not working correctly.	
	Level control valve has no apparent problem but setting is incorrect.	Adjust level control valve setting.
	Malfunctioning level control valve.	Consult control valve manufacturer guidelines for servicing and recommissioning.
	Problem with pump level switch that controls reservoir level.	Service/replace pump level switch.
Zone boundary	Open boundary valve, which causes high pressure to enter the zone and causes the reservoir to overflow due to backflow into reservoir.	Check and ensure that all known boundary valves are closed.

Table 28: Reservoir run-dry guideline

Location	Possible Cause	Possible Remedy
Reservoir	Reservoir level control valve not working correctly.	
	Level control valve has no apparent problem but setting is incorrect.	Adjust level control valve setting.
	Malfunctioning level control valve.	Consult level control valve manufacturer guidelines for servicing and recommissioning.
	Problem with pump level switch that controls reservoir level.	Service/replace pump level switch.
Supply to reservoir	There is insufficient or no supply to reservoir.	Investigate bulk water system upstream of reservoir to identify cause for insufficient or no supply.

Location	Possible Cause	Possible Remedy
Water network	Open boundary valve, which causes water to flow out of zone and drain the reservoir.	Check and ensure that all known boundary valves are closed.
	Burst pipe causes reservoir to drain.	Locate and repair burst pipe.
	High leakage causes reservoir to drain.	If no apparent visual bursts can be located, use flow-logging data for night flow analysis to determine the extent of leakage in zone. If the leakage is high, a project should be undertaken to address leakage (e.g. pressure management, active leakage control, on-site leak repair).

Table 29: Consumer meter accuracy complaint guideline

Location	Possible Cause	Possible Remedy
Consumer meter	Leakage at consumer resulting in high water bill. Consumer claims problem is caused by meter inaccuracy.	Log flow for consumer and establish level of leakage. Determine if leakage could have caused the high water bill.
	Meter problem.	If there is little or no leakage at consumer and a meter problem is suspected, the meter can be removed and tested at an accredited facility. Alternatively, a new check meter can be installed in series with the existing consumer meter to test the accuracy of the existing meter.

REFERENCES

McKenzie R, 1999, Sanflow Night Flow Analysis User Guide, WRC Report TT109/99, ISBN1868454908, Water Research Commission, Pretoria, June 1999.

McKenzie R, 2001, Presmac Pressure Management Program User Guide, WRC Report TT152/01, ISBN18684572222, Water Research Commission, Pretoria, April 2001.

Westman T, 1990, The Processing of Logger Data for Municipal Applications.