Kobus Prinsloo
SSIS Sahara (Pty) Ltd
kobus@saharaspy.co.za

Hydraulic modelling and field verification on the **Withoogte to Besaansklip bulk water supply pipeline**

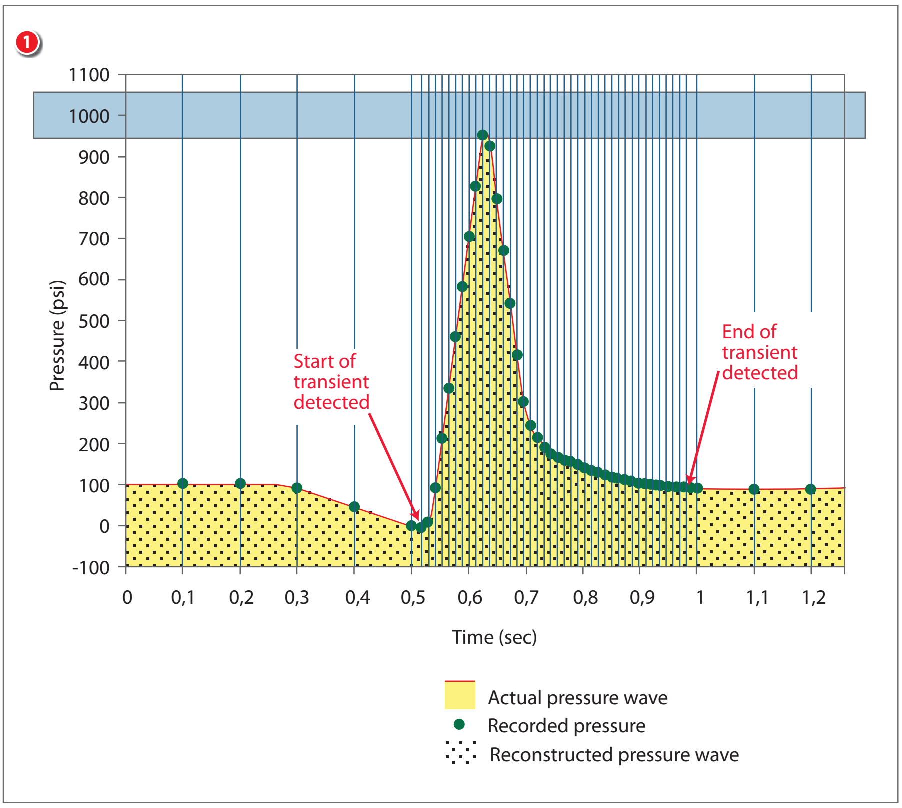
INTRODUCTION

A change in the steady state operating condition of a fluid system, unintentionally by means of the closure of a valve or unplanned pump operational change, or due to system failure, is communicated to the system by pressure waves propagating from the point of origin in the system at which the change in steady flow condition had been imposed. The system attains a new state of equilibrium, after some time, if the change has not reached destructive proportions. The terms "surge", "water hammer" and "transient flows" are used synonymously to describe an unsteady flow of fluids in a pipe system.

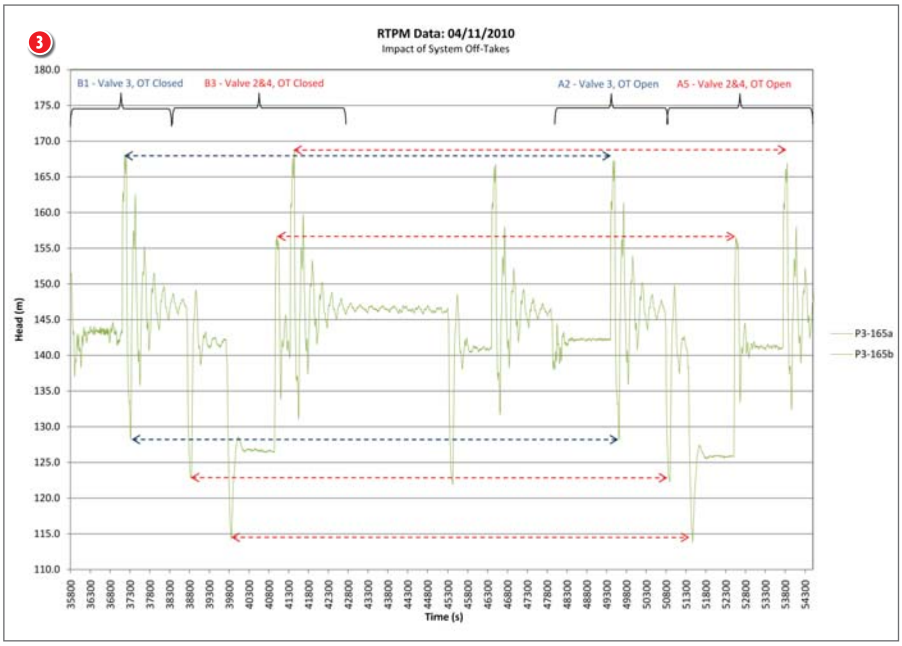
Pressure transients can cause extensive damage to water distribution systems, from catastrophic pipeline failures on the one hand to less obvious or visible (but often more widespread and dangerous) long-term effects like damaged pipeline seals and long-term cyclic fatigue loading on the pipe wall, leading to higher than expected operation and maintenance costs, extended periods of non-functionality, reduction in the service life of the infrastructure, increased water loss and even intrusion of contaminants into the distribution system.

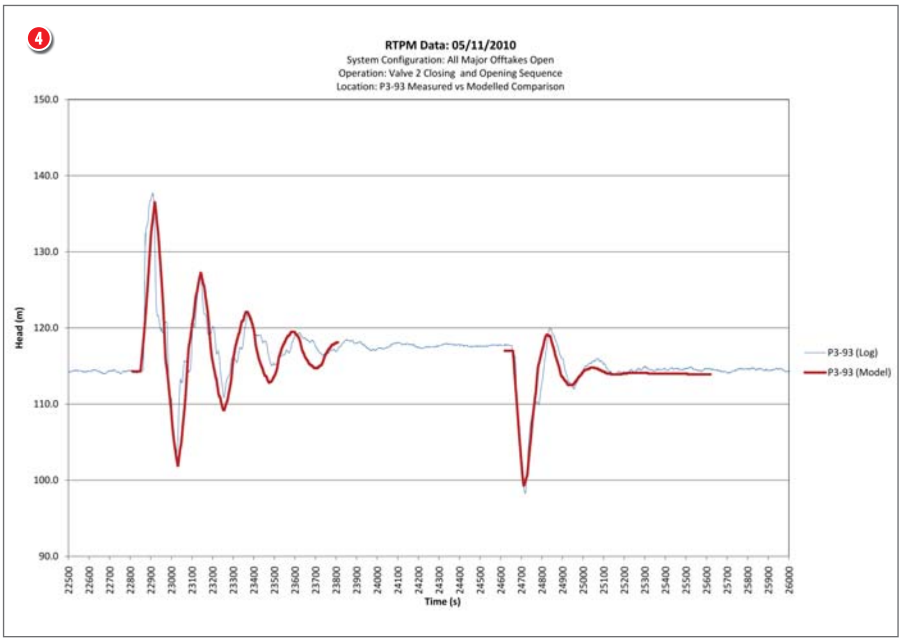
BACKGROUND

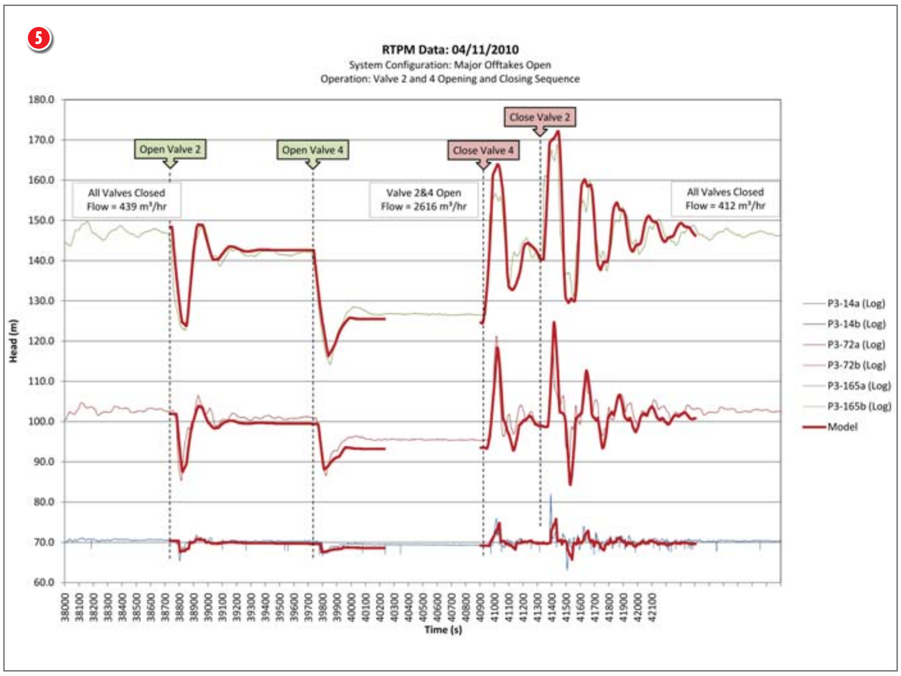
The West Coast District Municipality (WCDM) is responsible for the bulk water supply to the southern West Coast region of the Western Cape. The Withoogte to



1 Typical RTPM pressure recording
2 Typical RTPM site arrangement illustrating pressure transducer connection at an air valve installation, protective box containing the battery and logger unit, and the GPS receiver in the foreground







Besaansklip Reservoir pipeline is a strategic component of the bulk supply system. The pipeline conveys water under gravity from the Withoogte Water Treatment Works (WTW) near the town of Moreesburg to the Besaansklip Reservoir near the Port of Saldanha over a distance of 62,7 km via a pre-stressed concrete and steel pipeline with diameters varying between 1 100 and 1 500 mm. The flow into the Besaansklip Reservoir is controlled through four remotely operated flow control valves and one bypass connection that always remains open. The normal operating approach is to maintain stable reservoir levels in both the Withoogte and Besaansklip Reservoirs by continuously adjusting the flow rate into the Besaansklip Reservoir.

The WCDM recently completed a comprehensive leak detection survey as part of a pro-active program to assess the condition of their bulk water supply infrastructure. The investigation was performed by SSIS Sahara (Pty) Ltd (SSISS) using the precise Sahara® leak detection system. During the Sahara inspections on the Withoogte to Besaansklip pipeline, it was observed that operational changes (opening and closing of valves) were performed at a relatively fast rate. Pressure surges on gravity pipelines are very sensitive to the rate of operational change, and although the existing approach does not subject the pipeline to peak pressures leading to regular pipe failures, it was agreed that it would be very valuable to have a better understanding of the impact that the current operational regime has on the transient pressure behaviour of the pipeline, and whether the magnitude of pressure surges could be reduced by implementing operational changes.

3 Measured pressure variation during similar operating scenarios, with the major system off-takes closed and then open, illustrating the negligible difference in the magnitude of the maximum and minimum pressures

4 Measured versus modelled comparison during a valve closing and opening sequence

5 Measured versus modelled comparison during valve opening and closing at three different locations along the pipeline

6 Modelled pressure variation at different locations along the pipeline following three different valve opening and closing times

7 Reduction in the maximum/minimum pressure amplitude along the pipeline due to an increase in the valve operating time from 30 seconds (red envelope) to 240 seconds (blue envelope)

SSISS was subsequently commissioned to compile a hydraulic model of the Withoogte to Besaanklip pipeline in order to mimic the steady state and transient behaviour of the pipeline following various operational scenarios. The hydraulic model was compiled using the Surge 2010 analysis software and calibrated against actual measured pressure data captured on site using Remote Transient Pressure Monitors (RTPM).

REMOTE TRANSIENT PRESSURE MONITORING (RTPM)

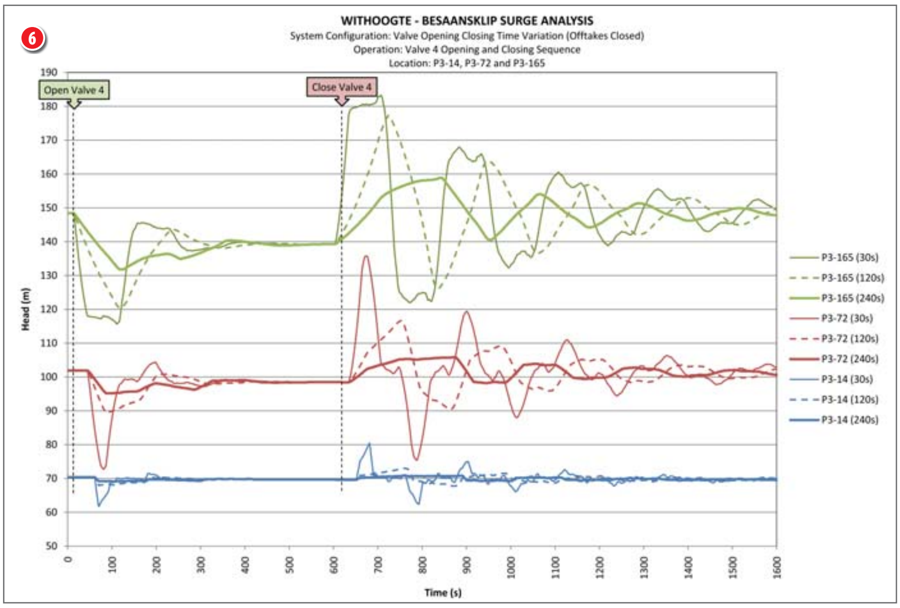
In order to calibrate the steady state and dynamic models, actual pressures were measured by RTPM devices. The RTPM records the variation of pressures within a pipeline and has the ability to 'sense' the approach of a pressure transient and to automatically increase the rate of data capturing to ensure that the surge event is accurately recorded. The pressure measurement device can therefore be used to measure both static and dynamic pressure variations over long periods.

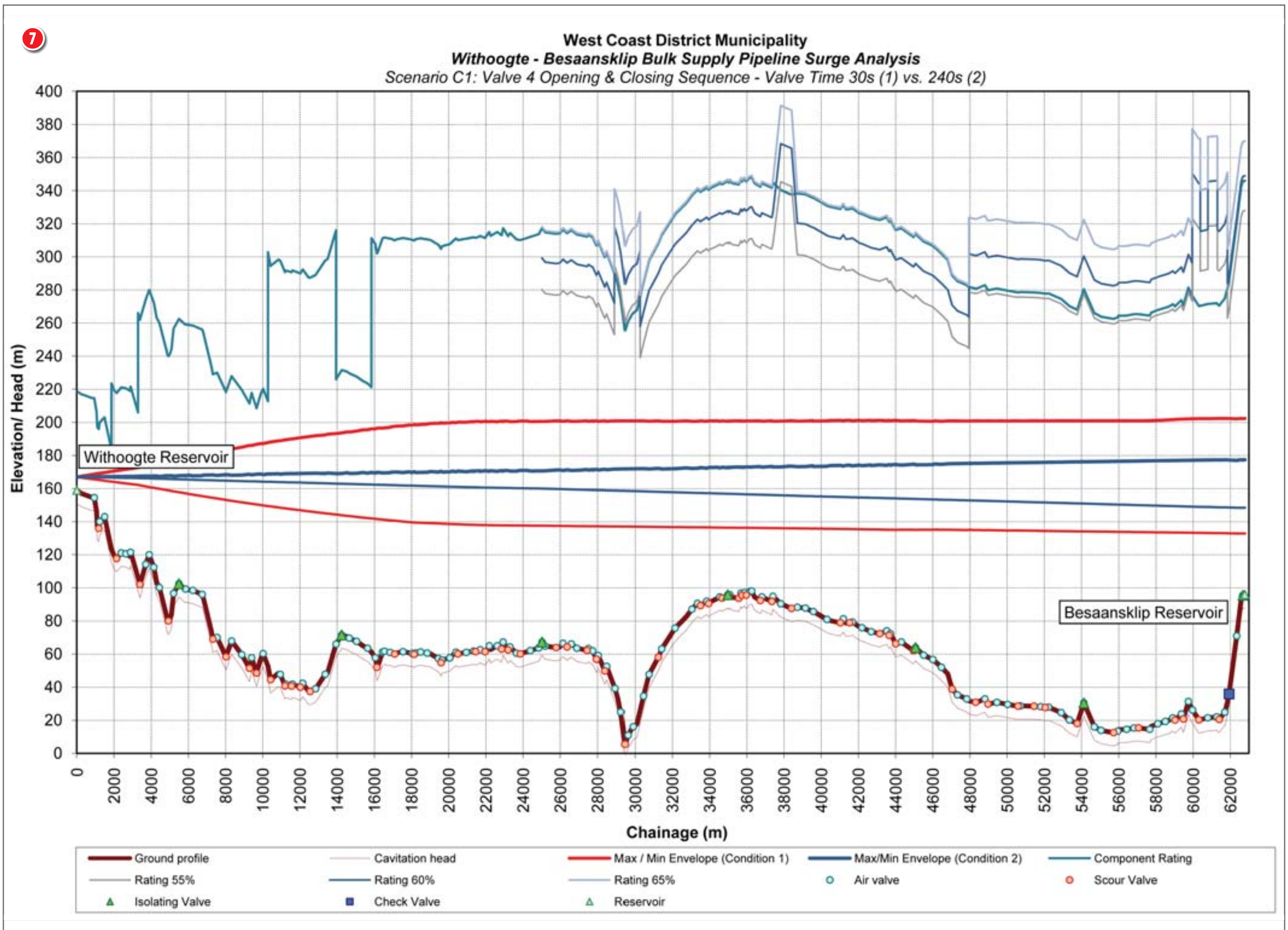
The system's features include the following:

- RTPM is portable and easy to operate and install.
- Pressure sensors can operate at any range of pressure, including negative pressures.
- The units feature user programmable recording intervals and transient detection trigger settings.
- The units have GPS receivers to ensure time synchronised logging at all locations along the pipeline.

A typical pressure/time plot is illustrated by Figure 1 and the typical RTPM site arrangement is illustrated by Figure 2.

The RTPM records the variation of pressures within a pipeline and has the ability to 'sense' the approach of a pressure transient and to automatically increase the rate of data capturing to ensure that the surge event is accurately recorded





PIPELINE PARAMETER VERIFICATION AND HYDRAULIC MODELLING

The data gathered with the RTPM was used to confirm the following parameters and calibrate the hydraulic model:

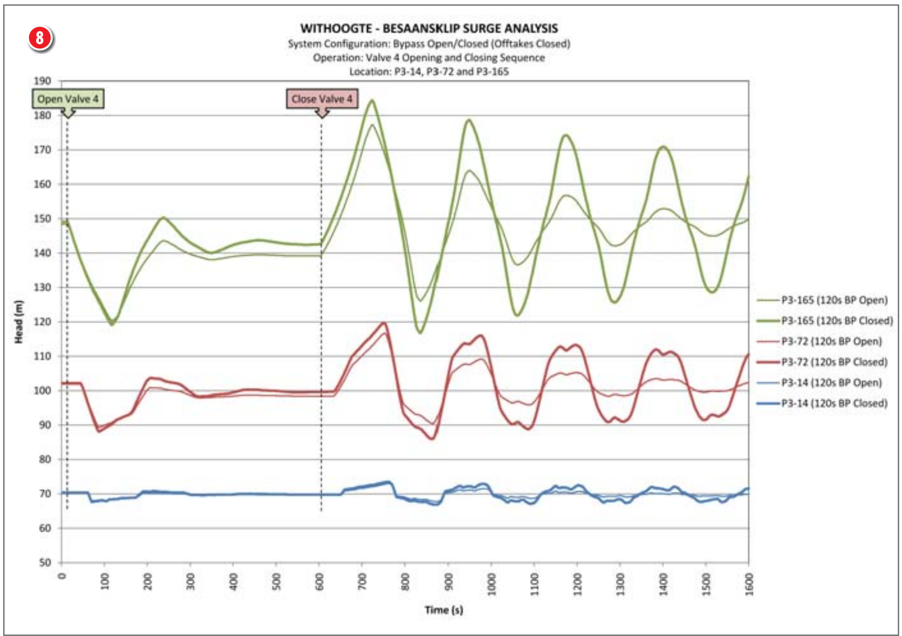
- **The impact of system off-takes:** Major off-takes along a pipeline can reduce the magnitude of pressure surges or contribute to a faster dampening of the pressure waves in a system. The data gathered on the Withoogte-Besaansklip pipeline however confirmed that the influence of the off-takes was negligible on this system (Figure 3).
- **Wave celerity:** The GPS synchronised readings at different locations along the pipeline were used to calculate the wave celerity of pipe sections of similar diameters and materials.
- **Steady state hydraulic performance and absolute roughness:** Good correlation was achieved between the measured and modelled steady state pressures with the model predicting pressures to within 5% of the measured values at an absolute roughness value (k_s) of 0,35 mm for similar flow conditions. The calibrated model was used to confirm the maximum hydraulic capacity of the pipeline in its current condition, which is important from a long-term planning point of view.
- **Transient behaviour:** Good correlation was achieved between the modelled and measured surge results. The wave

8 Modelled pressure variation at different locations along the pipeline with the by-pass on the Besaansklip inlet manifold open and closed

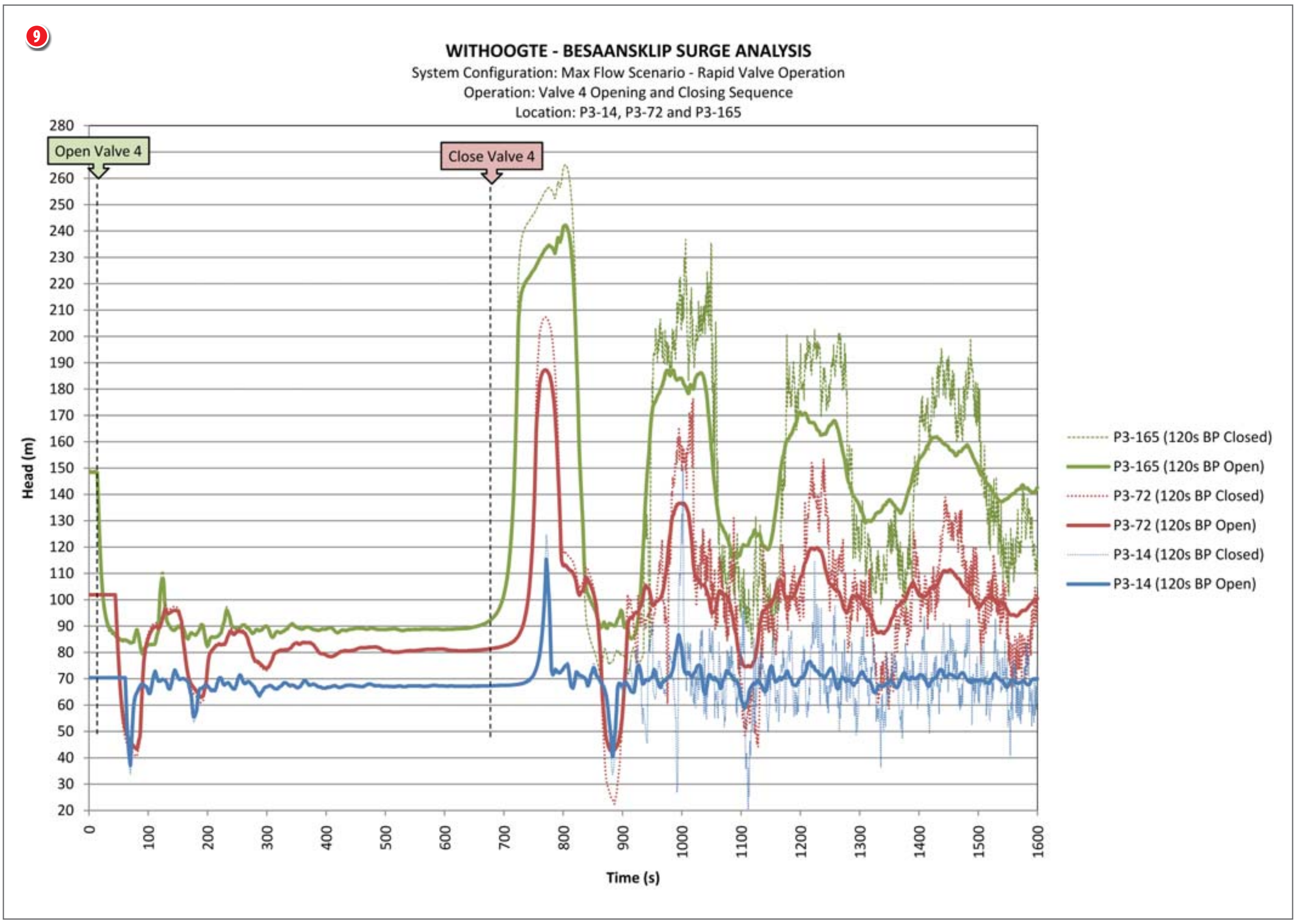
9 Modelled pressure variation at different locations along the pipeline following simultaneous rapid valve closure under peak flow conditions with the by-pass on the Besaansklip inlet manifold open and closed

10 Maximum and minimum pressure envelopes following simultaneous rapid valve closure under peak flow conditions with the by-pass on the Besaansklip inlet manifold open (blue envelope) and closed (red envelope)

8



9



celerity and transient behaviour of the system were therefore accurately reflected by the Surge 2010 hydraulic model, and the model could be used with confidence to analyse further operational scenarios. Figures 4 and 5 illustrate the correlation between the measured and modelled pressure variation following the execution of similar operational changes in the physical and simulated environments.

RECOMMENDATIONS

Using the calibrated hydraulic model, a number of operational variations were modelled to determine its impact on the induced pressure surges. The expected maximum and minimum pressure envelopes along the pipeline were generated to illustrate the maximum and minimum pressures along the entire route to confirm that the maximum pressures did not exceed acceptable values. Some of the operational scenarios which were evaluated are described below:

Valve operating times

The impact of increasing the valve opening and closing times was assessed. Figure 6 clearly illustrates the benefit of increasing the valve opening and closing times. Even though short operating times do not result in pressure surges that are higher than the rated capacity of the pipeline under the current normal flow conditions, it is clear that increasing the valve operating time, significantly reduces the extent of pressure variation on the system and therefore reduces the amplitude of cyclic loading (as shown in Figure 7).

Effect of the open by-pass into Besaansklip Reservoir

Under current normal operating flows, it was found that the open by-pass connection into the Besaansklip Reservoir did not contribute to a significant reduction in the magnitude of pressure surges. The open by-pass did, however, result in the faster dampening of the pressure waves as illustrated by Figure 8.

Maximum flow condition – rapid valve closure

The impact of a rapid and simultaneous valve closure under peak flow conditions, and with the by-pass open and closed, is illustrated by Figures 9 and 10. The high surge pressures that could be generated under peak flow conditions reiterated the importance of implementing strict operating rules to prevent the simultaneous closure of multiple valves.

Based on the surge modelling, recommendations were made with regard to the minimum allowable valve operating times, acceptable time delays between subsequent valve operations, and operational safeguards to ensure that the pipeline is not overstressed, and also to reduce the cyclic pressure amplitude caused by normal operational changes.

CONCLUDING REMARKS

"Following the pressure monitoring and hydraulic modelling of the Withoogte-Besaansklip pipeline, we now have a much better understanding of the hydraulic performance and behaviour of this pipeline and the impact of operational changes on the system. We can now also investigate the impact of any operational change and demand variations on the system with confidence." So says Nic Faasen, Manager: WCDM Water (bulk water service provider to 22 towns in the West Coast). □