REWORKING THE OLD TO PROVIDE THE NEW: THE RICHMOND WATER TREATMENT PLANT

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ABSTRACT

The town of Richmond's water supply started as two independent systems both delivering non-compliant water with different infrastructure.

The question was what could be made out of this mix of existing infrastructure to provide a sustainable supply of compliant water? The answer came in the form of a new water treatment plant and a re-shuffle of existing infrastructure. Reaching the end result was not easy given the tight budget, but clever solutions ensured success.

Blending of the two source waters elegantly reduced nitrate to safe levels while at the same time optimised use of the consented abstraction limits. This, along with modifications to existing bores, enabled the treatment process to be simplified to rely on UV treatment and pH adjustment alone.

With the majority of the existing trunk mains being asbestos-cement, an initial investment into understanding the limitations of these mains enabled re-use of infrastructure and a change-of-use of one of the large trunk mains.

Today, the original goals of the project have been met and Richmond's water supply is secure well into the future. This paper describes how these goals were achieved and shares some of the key learnings.

KEYWORDS

Security of supply, AC pipe, water treatment, infrastructure reuse, hydraulic modelling, surge

1 INTRODUCTION

The success of the Richmond Water Treatment Plant (WTP) project largely started by understanding the old in order to provide the new. Today, the town of Richmond has a modern WTP that continuously supplies a safe, secure and compliant water supply, but getting there wasn't easy.

A significant effort was spent defining the pipework modifications that were required to provide the most cost effective solution. Ultimately a solution which included a combination of new pipe, re-use of existing pipe, new cross connections and a change of use of one of the pipelines from treated to raw water was established. Blending of the two raw water sources was taken as an essential requirement since this would reduce the need for expensive treatment, improve the security of supply and maximise the existing consented abstraction limits.

The next step was to determine if the pipelines could be re-used since the vast majority of the trunk mains were asbestos cement (AC) pipe. Although these pipes had no history of failure, there was a poor understanding of the actual condition of the pipes and they also ranged in size and pressure class. This in turn created a low level of confidence as whether these AC mains could be re-used without failing under different future operating conditions.

The project team used pressure monitoring and modelling to understand the pressures currently experienced within the pipelines. From this acceptable maximum and minimum pressure limits for each pipeline were established. While this approach was taken to be conservative, modelling indicated that the modified system with the new WTP could operate within these defined limits.

A surge analysis was conducted and it was determined that surge vessels were required at the WTP. Vessels were required on each of the two raw water delivery mains to eliminate negative surge pressures, which would be harmful to the UV reactors. On the two treated water systems, surge vessels were required to reduce both positive and negative pressures. During commissioning, the surge model was used to help commission the surge vessels thereby potentially saving days on site during what is normally a trial and error process.

These initiatives are described in this paper.

2 PROJECT OVERVIEW

This project involved a new water treatment plant (WTP) for the town of Richmond, designed to meet Drinking Water Standards. The project included:

- a new 15,400m3/day capacity treatment plant and 1,500m3 balance tank on a greenfield site,
- the installation of over 4km of large diameter pipe (up to 450mm-dia) on both the raw and treated side of the WTP,
- change of use of existing pipelines and upgrades to the two primary bore fields.

The Waimea WTP, which is located between the Waimea bores and the new WTP was retained in order to continue to supply the Mapua area. A basic schematic of the scheme is shown in Figure 1.

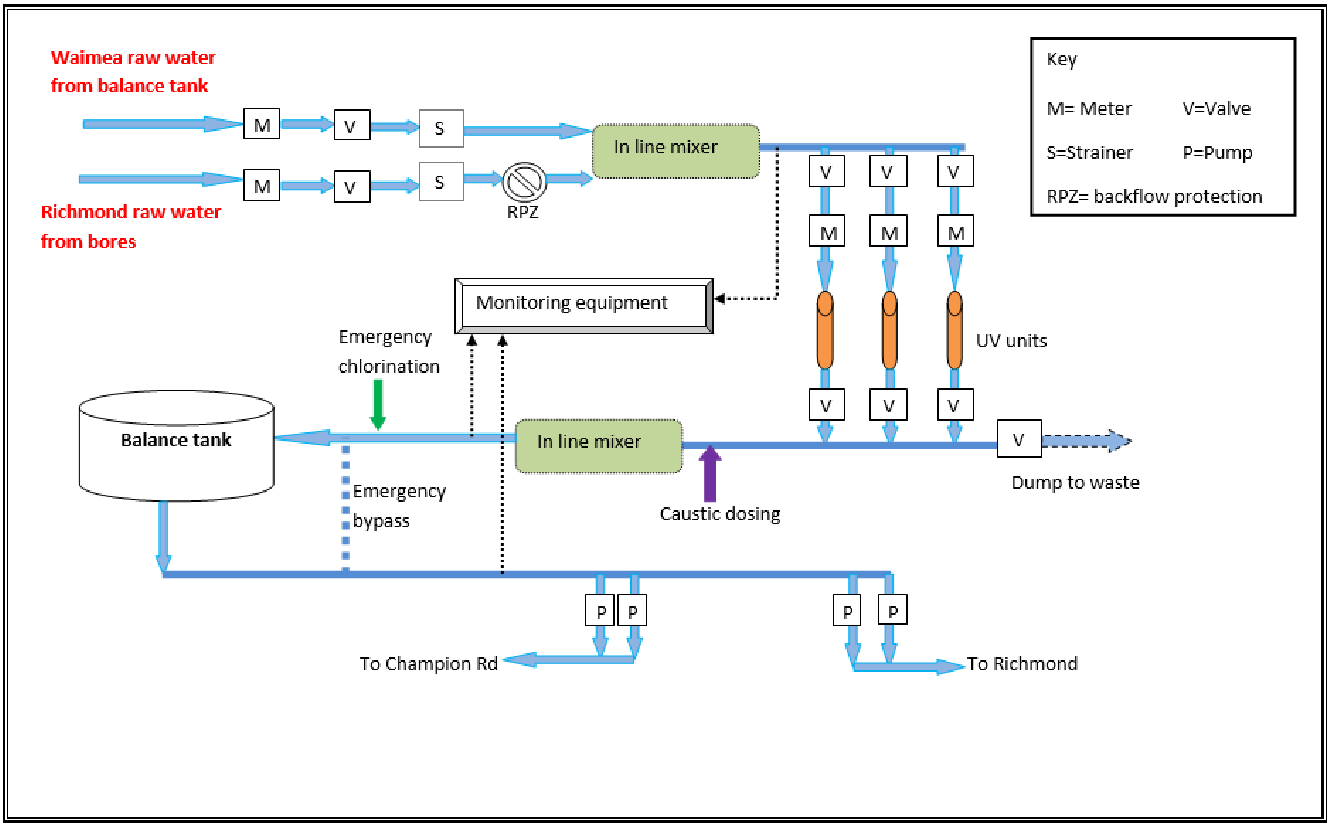


Figure 1: Richmond WTP Schematic

The water supply network for Richmond was historically divided into two supply zones with the Waimea bores supplying the Waimea Zone and the Richmond bores supplying the Richmond zone. A unique control strategy was developed for blending the two source waters (refer to Section 3 below), and today the WTP has the ability to run off one or both raw water sources. The WTP has two sets of high lift pumps, thus maintaining the two separate supply zones (refer to Figure 2 and 3).

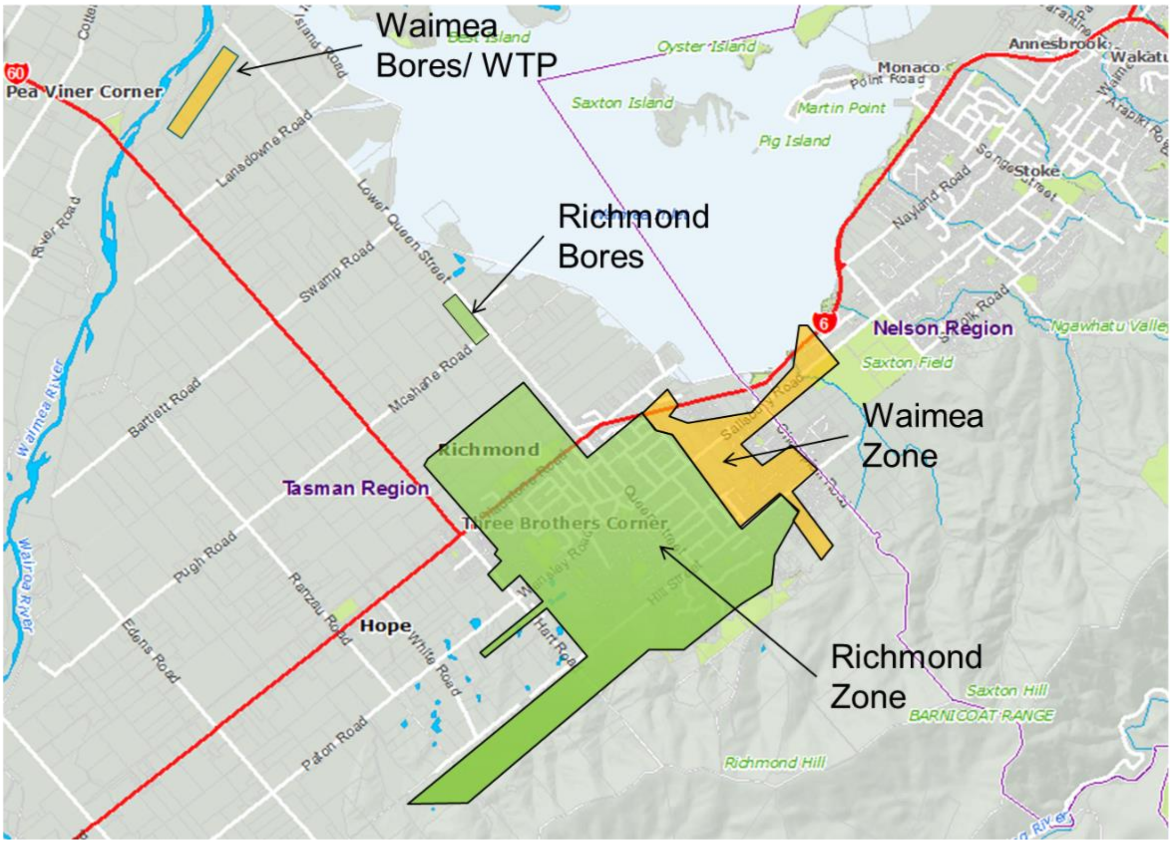
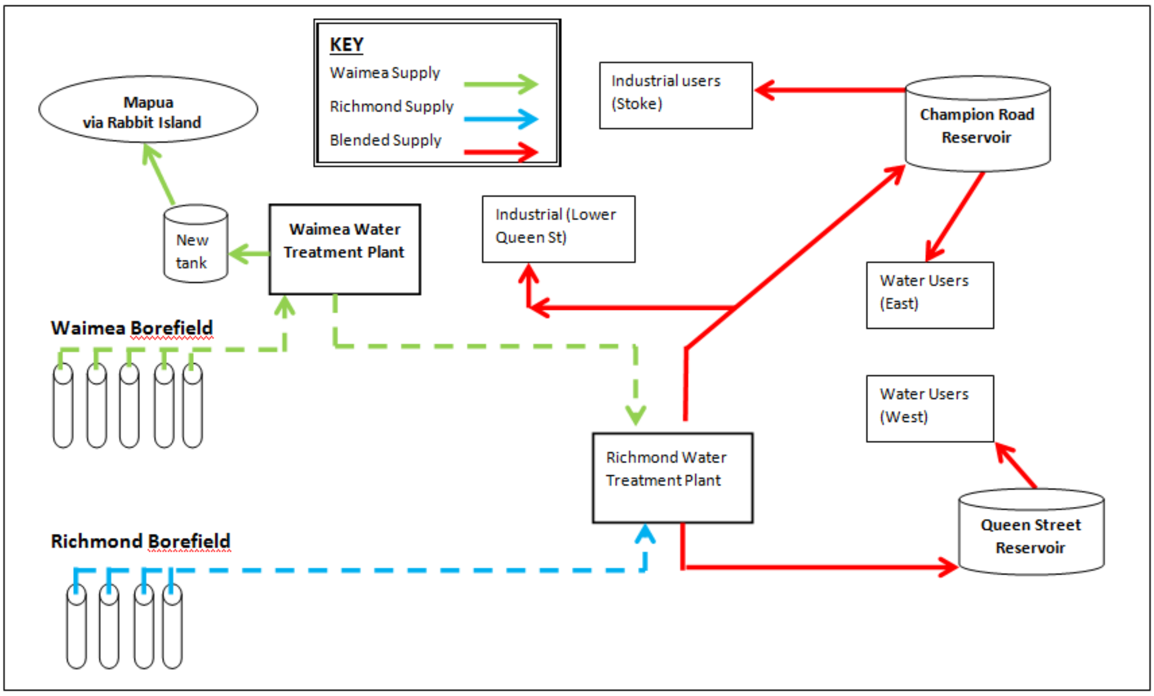


Figure 2: Richmond Supply Zones



New Water Network System for Richmond

Figure 3: Richmond Supply Schematic

The WTP is based on attaining a 3-log level of protozoa de-activation and therefore treatment was based on using UV treatment. The plant also has facilities for pH adjustment using caustic soda and for chlorination, the latter is anticipated to be used only during emergency conditions. The treatment building and layout of equipment has been designed to allow future expansion of the building and additional treatment equipment to be added in the future, should this be required.

The project utilised Council's hydraulic model, modelled in InfoWorks and included pre-existing and planned future improvements within the network. This model proved to be fundamental to ensuring success of the design of the pipe network and pumping design. The model was converted to H2OMap format in order to easily transition to surge analysis using the surge platform H2OMap Water-SURGE.

3 BLENDING

Nitrate levels in the Richmond bore source water were historically consistently above the maximum acceptable value stated in the Drinking Water Standards. However, the Waimea bore source water has relatively low nitrate levels. The two bore source waters were therefore blended at the new WTP to reduce nitrate to acceptable levels. The option of blending avoided the need for costly nitrate removal treatment. In this case blending was a form of treatment.

A unique control philosophy was developed to maintain a blended ratio of approximately 60% Waimea to 40% Richmond bore water in order to maintain a nitrate concentration in the treated water of less than 25 mg/l NO_3, or 50% of the MAV. This is shown in Figure 4. Today the WTP has the ability to run off one or both raw water sources, thus giving the plant greater operational flexibility and improve the security of supply.

Coincidentally, and quite nicely, blending at this ratio also maximises the consented abstraction limits from the two well fields. The consented abstraction take for the Waimea wells is approximately twice that of the Richmond well, yet there is a higher demand in the Richmond Zone. Without the WTP and blending, the Richmond wells would have started to limit the supply. However, with the WTP, as a result of blending, supply of additional water from the Waimea wells will effectively relieve the demand from the Richmond wells. The future demand will be better balanced between the two well fields.

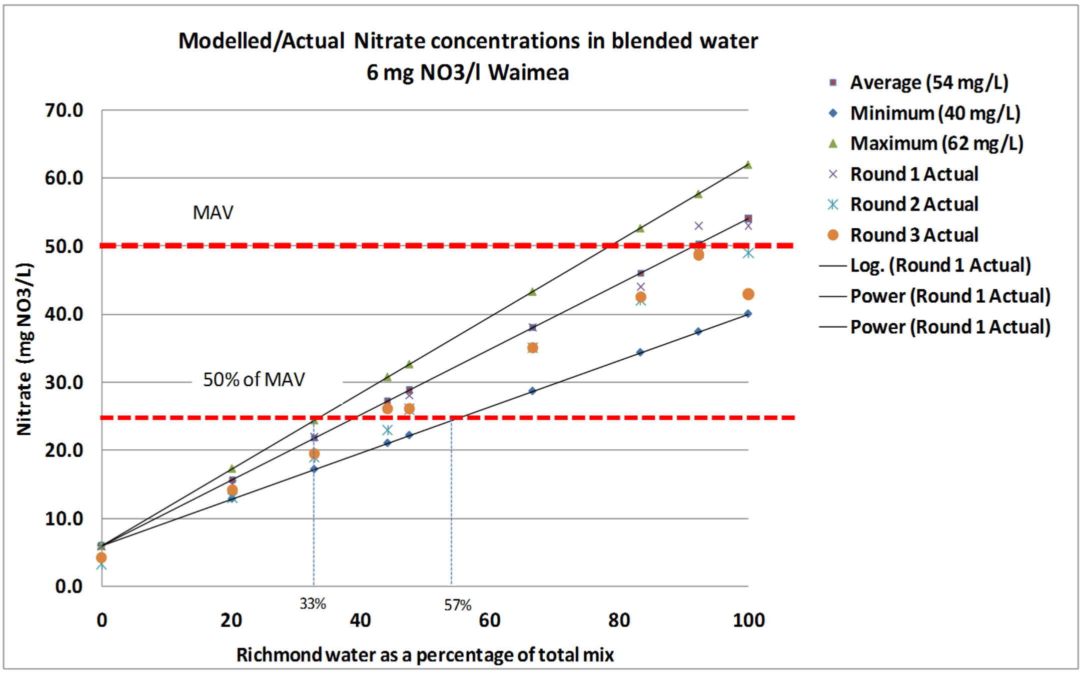


Figure 4: Nitrate Levels of the Blended Water

4 REUSE OF EXISTING PIPES

4.1 DESIGN LIFE OF EXISTING AC PIPE

The vast majority of the Richmond and Waimea trunk mains were Asbestos Cement (AC) pipes installed in the 1970s and there was originally uncertainty as to how these mains would cope under modified conditions once the WTP was built. There was also uncertainty associated with the remaining life of these AC pipe. In order to gain a better understanding of these uncertainties, an assessment was undertaken to quantify acceptable operating pressures (both maximum and minimum).

4.1.1 LITERATURE REVIEW OF ASBESTOS CEMENT PIPES

Key findings of from a review of the New Zealand Water and Wastes Association (NZWWA) “Asbestos Cement Watermain Manual”, 2001, were:

- Unlike most other pipe materials, softening of the pipe walls is known to be occurring in AC watermains and hence structural failure of these pipes is inevitable.
- The issue of life expectancy of AC watermains is a very important one for water supply authorities in terms of renewal planning, funding / depreciation issues and maintaining acceptable levels of service.
- The results of the analysis confirm that the deterioration of AC pipe is not an exact science, and there are significant variances across samples.
- A deterioration model was developed to help estimate the useful life of the pipe.
- Charts have also been prepared showing the range of predicted years to failure to give the reader some idea of the variation between samples.
- Larger diameter AC pipes have performed better than smaller diameter AC pipes.

In relation to the Richmond and Waimea trunk mains, the following observations can be drawn from the NZWWA manual.

RICHMOND TRUNK MAINS

- Existing pipes are 250mm, 300mm and 375mm, Class D, AC pipes. These have an allowable design pressure of 120m.
- The NZWWA manual does not contain any information about potentially increasing the operating pressure of an AC pipe from the pressure it has historically been used to.
- For this reason it was accepted that the acceptable proposed pressures would be generally limited to the historical pressures.
- The pipes were installed in early 1970s and were 40 years old.
- There has been no history of bursts or major leaks on the trunk main.
- Based on the 80m of operating pressure on the main over its lifetime, the predicted years for failure from the NZWWA manual is detailed in the Table below. This was based on the deterioration curves provided in the Asbestos Cement Watermain Manual. Upper 85% in the table below means that 85% of the samples were below this band. Similarly the lower 85% means that 85% of the samples were above this predicted life.

Table 1: Richmond Main – Predicted Remaining Life

Deterioration Curve	Predicted Years to Failure	Remaining Life
Upper 85%	180	140 years
Upper 50%	130	90 years
Medium	100	60 years
Lower 50%	80	40 years

Lower 85%	55	15 years

There is a massive difference in the predicted useful life of the pipeline from the charts in the NZWWA manual.

The conclusion drawn from this data is that even assuming the pipe is similar to the lowest strength trend lines in the AC manual, the pipe can be expected to have 15 years of remaining life, and a less conservative approach would suggest 40 years of remaining life.

WAIMEA TRUNK MAIN

The existing Waimea AC trunk main was more variable in terms of diameter and pressure class than the Richmond main.

- In general, the pipes in the vicinity of the bores for the Waimea WTP are Class B. These have a 60m design working pressure.
- The trunk mains along Lower Queen Street are a mixture of 375mm and 450mm dia. There are Class C pipe with a design working pressure of 90m.
- The Champion Road section is 450mm and is Class B, 60m allowable design pressure.
- This pipework was installed in 1975 and is approximately 40 years old.
- There has been no reported history of bursts or major leaks on the trunk mains.

The NZWWA manual does not contain any lifetime prediction charts for 450mm dia mains. The assessment was based on charts for Class B 375mm pipe.

This has a median predicted lifespan of 54 years. There are also no deterioration charts for the spread of results for Class B pipes. Curves were extrapolated for Class C pipe back on to the Class B pipes to give an approximation of the result.

This indicates that the lower 50% of life span for Class B pipe is less than 40 years. This means that the Class B pipe has limited useful remaining life, unless it has less than average deterioration.

The conclusion drawn from this review is that the Class B pipework near the Waimea bores had a limited lifespan based on the NZWWA manual. Renewal of the Class B pipes was likely required.

4.2 MINIMUM OPERATING PRESSURE OF AC PIPE

The buckling resistance of the AC pipes to withstand the potential vacuum and backfill loading was assessed using the Timoshenko equation to calculate the critical buckling pressure (Pcr). This equation assumes perfectly circular pipes and with no support from the ground. If buried, the capacity to resist buckling will be enhanced. If the pipe is not perfectly circular (some ovality), these buckling capacities will be reduced to approximately 70% of circular at 3% ovality.

The critical results from this exercise is that AC pipes have a very high resistance to buckling due to the thick wall thickness on the pipes.

The Class B 375mm dia pipe has the lowest Pcr against buckling. We have assessed the Pcr on the assumption that 50% of the wall thickness has deteriorated over time resulting in a 10mm wall thickness.

Even with this very conservative assumption, the pipe has a Pcr of 0.75 MPa. This gives a factor of safety (FOS) against buckling of 7.5. The 375 Class B pipe with a full wall thickness of 21mm has a FOS of 64.

The conclusion drawn from this exercise is that negative pressure (up to full vacuum) should not be a concern for the various AC pipes with respect to buckling.

However, negative pressure within the pipelines potentially result in ground water entering the pipework. While this is less of a concern for raw water pipelines, it must be avoided in the treated water pipelines. Furthermore, UV reactors (on the raw water pipes) are only certified to operate between 0 and 10 bar and exposure of negative pressures likely damage the reactors. For these reasons, a minimum acceptable pressure of 0-bar was adopted for the raw and treated pipelines.

4.3 MAXIMUM OPERATING PRESSURE OF AC PIPE

The methodology for assessing the maximum allowable pressure under steady state conditions was largely based ~~largely~~ on gaining an understanding of what pressures the network historically operated at safely. Other than one small section of pipe in the Richmond Zone, failure including bursts of existing AC main was rare. The balance tank at the new Richmond WTP will provide a hydraulic break between raw and treated water systems, therefore allowing these two systems to be analysed individually. Furthermore, despite blending of the two raw water sources, the two bore water supply mains were able to be individually considered. Likewise, the two sets of high lift pumps allowed the two treated water zones to be individually considered. In all, the network was split into four separate networks for the purpose of this analysis. The methodology adopted to determine the maximum operating pressure is summarised as:

- Run hydraulic model and determine modelled present day steady state pressures at key points in the network.
- Compare to actual surge measured in network. For this several high frequency data loggers were installed in the network at selected points in both the raw and treated systems.
- Determine from above two steps the maximum allowable surge pressures based on existing operating conditions.
- Review proposed high lift pump controls at new WTP and confirm run time, flow rates and pump sizes. Review static head and compare to present day conditions.

Results of this analysis are presented in the following four figures.

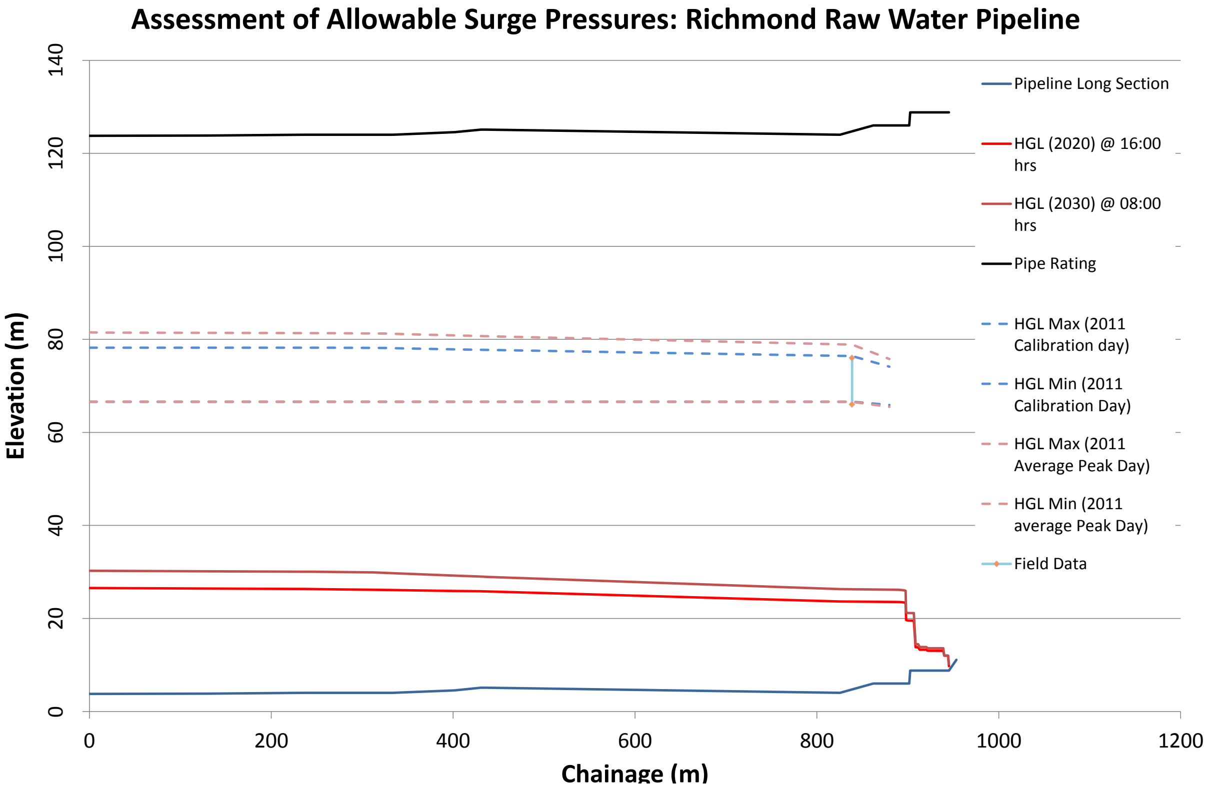


Figure 5: Allowable Pressure Assessment: Richmond Raw Water Network

Results of Figure 5 indicated:

- Future predicted steady state operating pressures at 2020 and 2030 were well below historical (2011) operating pressures and the pipe pressure rating. This was as a result of the bore pumps only pumping less than 1-km along a flat grade line to the new WTP, as opposed to having to pump to the high level reservoir, which is located at approximately 70m RL.

- The maximum acceptable surge and steady state pressure in the pipe was taken as the "HGL Max (2011 Average Peak Day), which was a model of average day-peak week conditions in 2011.

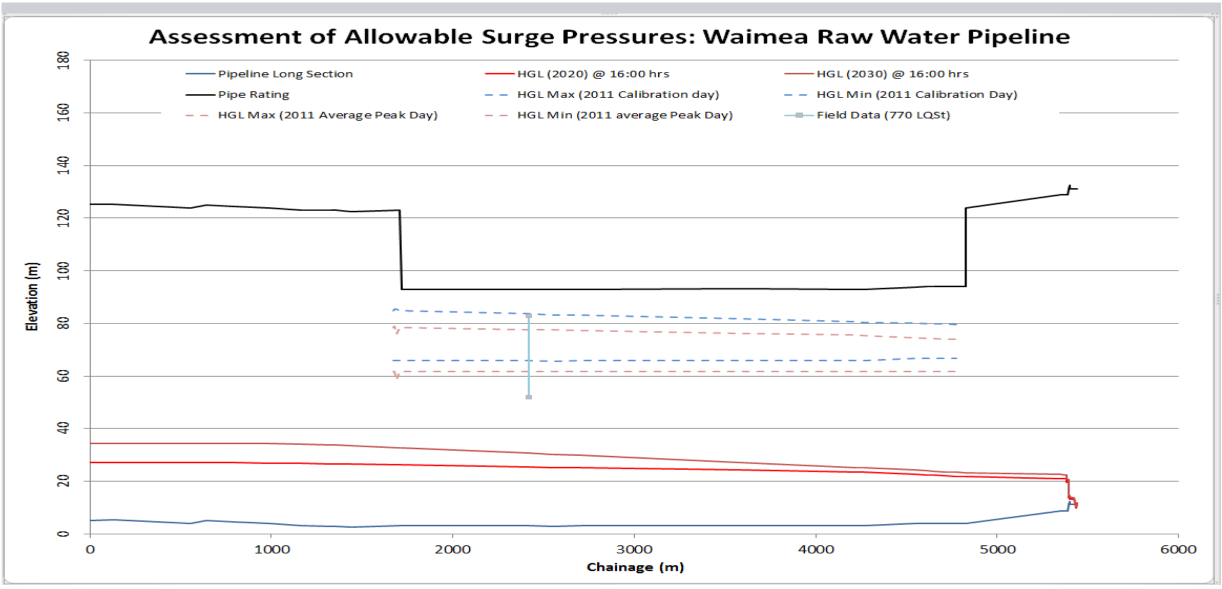


Figure 6: Allowable Pressure Assessment: Waimea Raw Water Network

Results of Figure 6 indicated:

- Future predicted steady state operating pressures at 2020 and 2030 were well below historical operating pressures and pipe pressure rating. This was as a result of the bore pumps only pumping along a flat grade line to the new WTP, as opposed to having to pump to the high level reservoir, which is located at approximately 65m RL.
- The maximum allowable surge and steady state pressures are as given by the "HGL Max (2011 Calibration Day" line

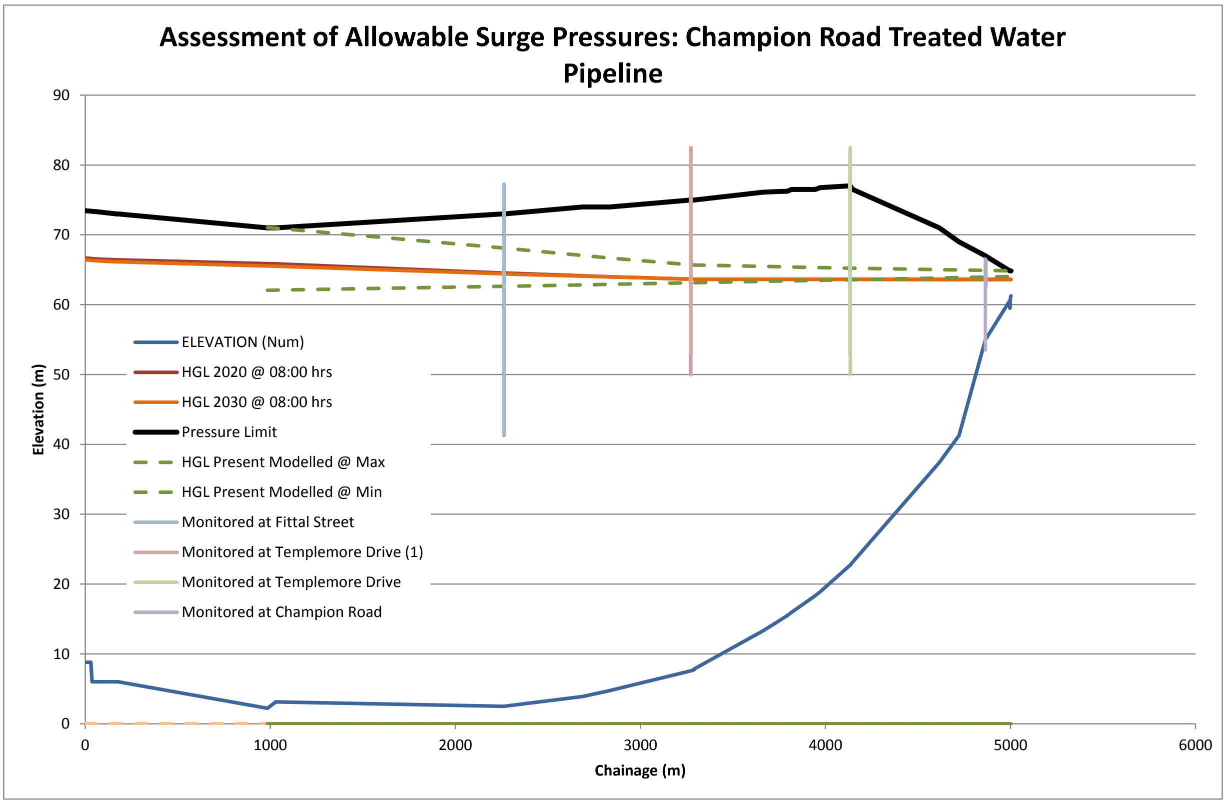


Figure 7: Allowable Pressure Assessment: Waimea Zone Treated Water Network

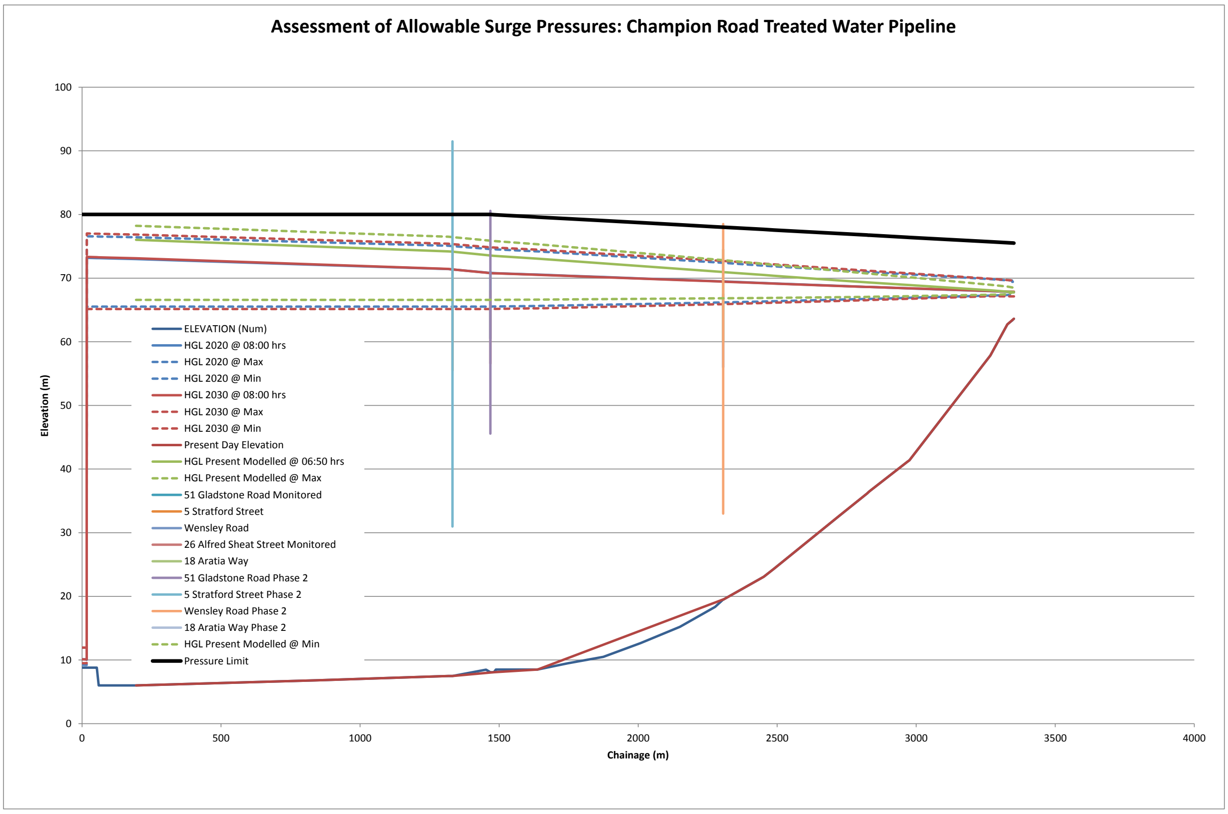


Figure 8: Allowable Pressure Assessment: Richmond Zone Treated Water Network

Results of Figures 7 and 8 indicated:

- The monitored pressures comfortably straddled the modelled pressures giving confidence to the results.
- The actual and modelled operating pressures were below the maximum pipe pressure rating of 120m for the Richmond Zone network.
- The actual and modelled operating pressures were below the maximum pipe pressure rating of 90m for the Waimea Zone network.
- The range of measured existing pressure in the pipelines was an indication of excessive surge in the existing system

There was the desire not to exceed existing maximum pressure limits under the future WTP scenario. Therefore, for the treated water systems, a maximum "Pressure Limit" was defined for both future treated systems that was determined from the results of modelling and measured pressure data.

Modelling indicated that the new WTP could supply future demands while operating at the adopted maximum pressure limits.

5 SURGE ANALYSIS

Once the limitations of the existing pipelines were defined in terms of allowable minimum and maximum working pressure, a surge analysis of the four pipeline systems was conducted using the surge platform H2OMap Water-SURGE. Results of the surge modelling are presented in the figures below.

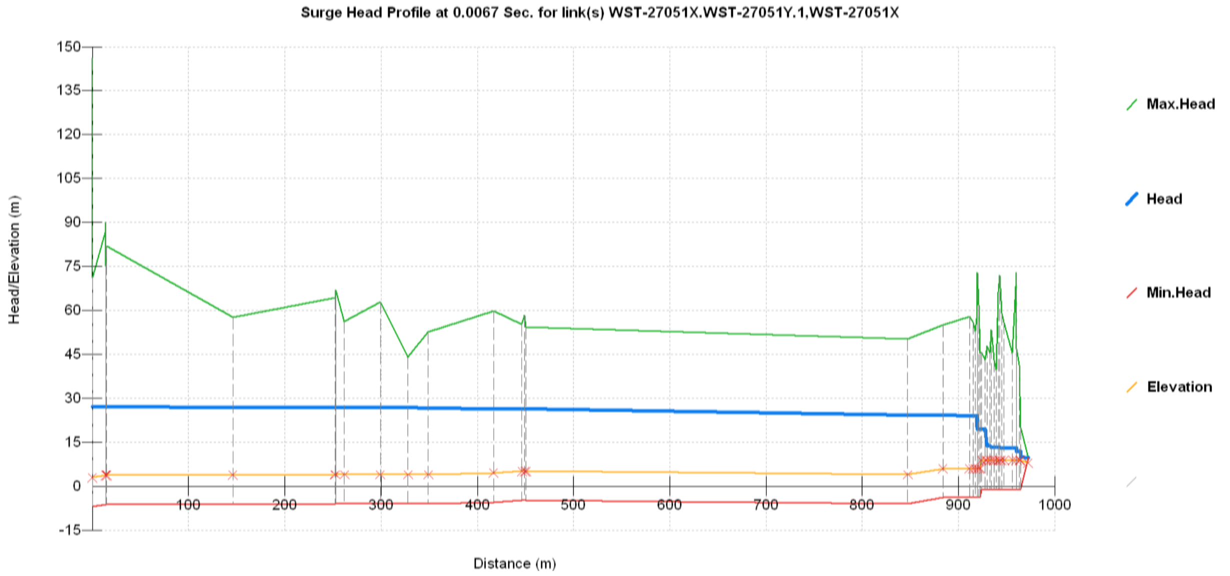


Figure 9: Richmond Raw Water Network Surge - Unmitigated

From Figure 9 it was concluded

- The modelled surge pressures are above the present-day maximum in-pipe pressure (approximately 80m), but below the pipe pressure rating of new Class D AC pipe (120m) in the vicinity of the upstream-most bore pump.
- Maximum surge pressures are within acceptable limits elsewhere on the pipeline
- The minimum pressures in the pipeline fall to full vacuum. The pipe itself can withstand full vacuum.
- However, this negative pressure is outside the acceptable limits for the UV units and mitigation of negative pressure for the UV units will likely be required.

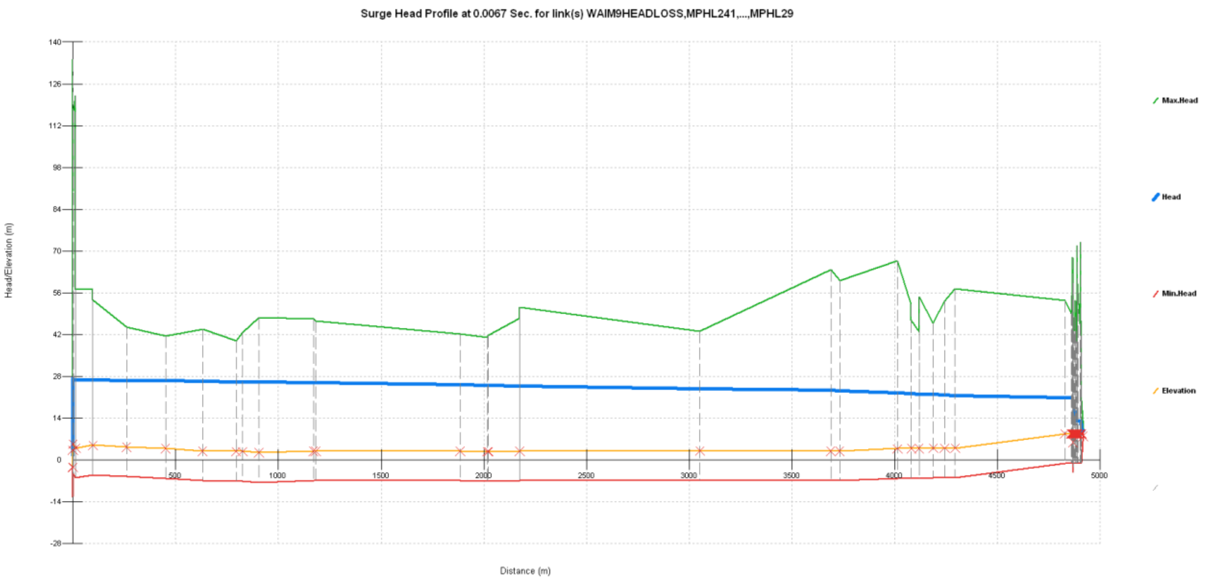


Figure 10: Waimea Raw Water Network Surge - Unmitigated

From Figure 10 it was concluded:

- The maximum surge pressure downstream of the Waimea WTP remains within the maximum allowable pressure.
- That upstream of the Waimea WTP (existing pipe Class B AC pipe) the maximum surge pressure is shown to be marginally below 60m. If these mains are not replaced then there is the associated risk of pipe failure.
- The minimum pressures in the pipeline fall to full vacuum. The pipe itself can withstand full vacuum.

- However, this negative pressure is outside the acceptable limits for the UV units and mitigation of negative pressure for the UV units will be required.

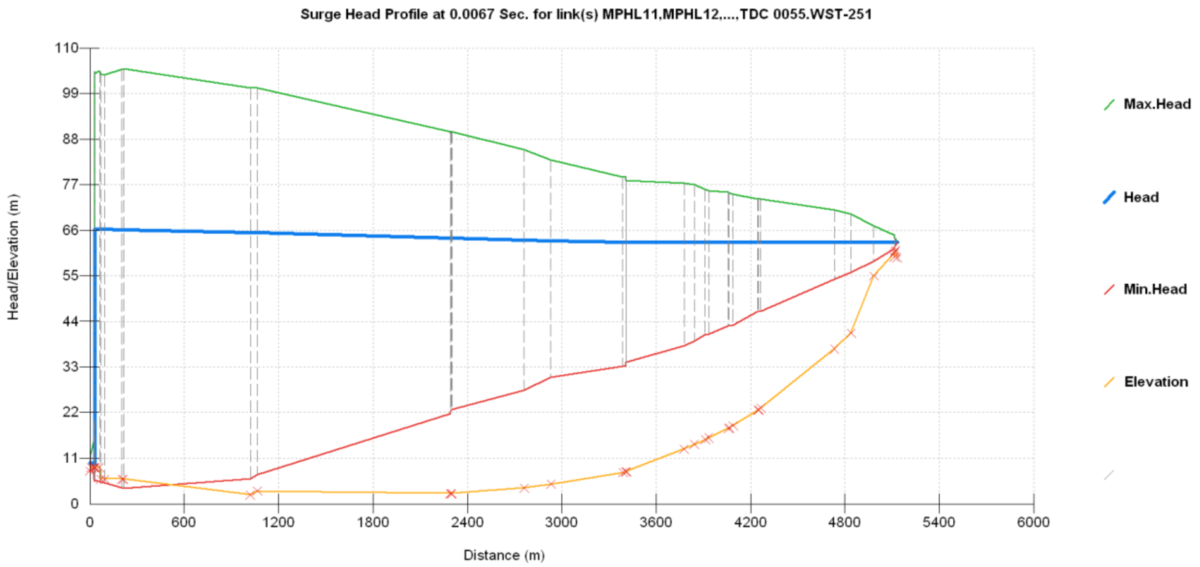


Figure 11: Richmond Zone Treated Water Network Surge - Unmitigated

From Figure 11 it was concluded:

- The maximum modelled surge pressure exceeds the established limit for this pipeline. The minimum surge pressure modelled is for the most part within the limit established for this pipeline, except for the first 500m of pipeline downstream of the pump station. Surge mitigation is required for positive and negative pressures.

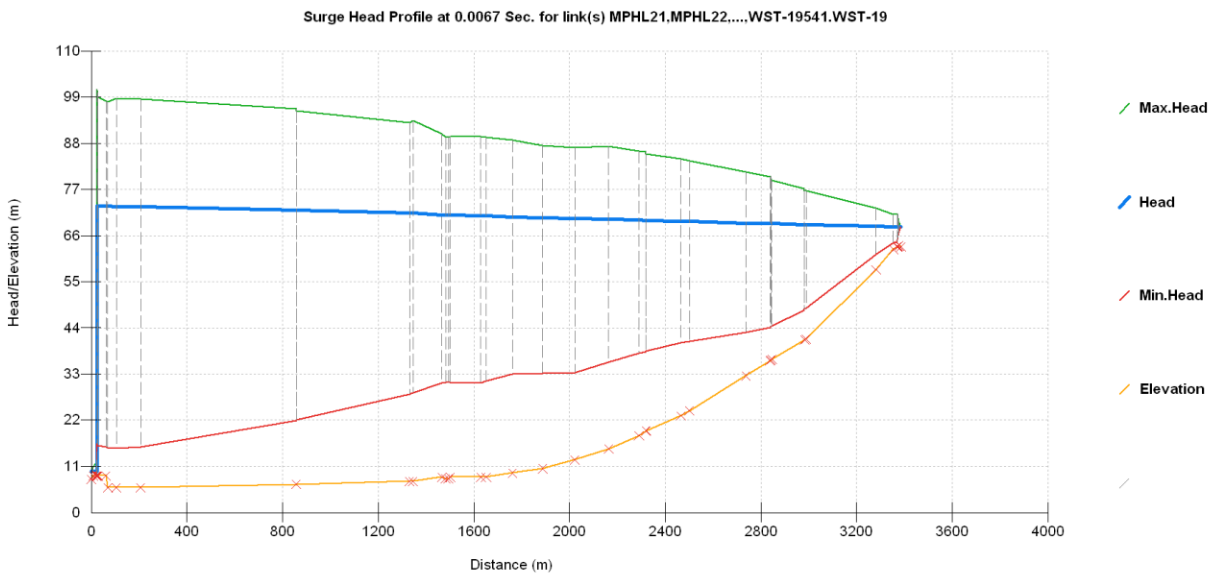


Figure 12: Waimea Zone Treated Water Network Surge - Unmitigated

From Figure 12 it was concluded:

- The maximum modelled surge pressure exceeds the established limit for this pipeline.
- The minimum modelled surge pressure is within the established limit for this pipeline.

5.1 SURGE MITIGATION

Variations to the surge analysis in the hydraulic model were conducted to determine the best surge mitigation strategy given the acceptable maximium and minimum pressure limits. Ultimately a surge vessel on each of the 4 systems was selected. As shown in Figures 13 and 14, a close correlation between the modelled mitigated surge and the actual mitigated surge (as measured during commissioning) was achieved.

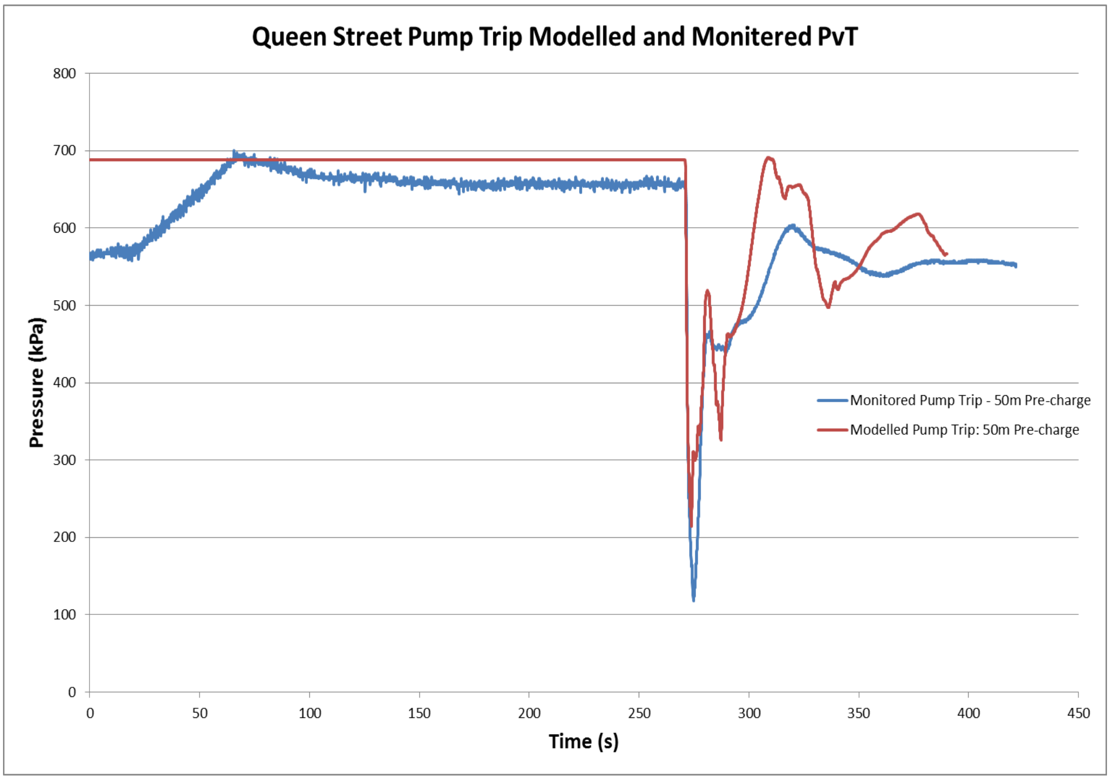


Figure 13: Richmond Zone Mitigated Surge Pressures: Modelled vs. Actual

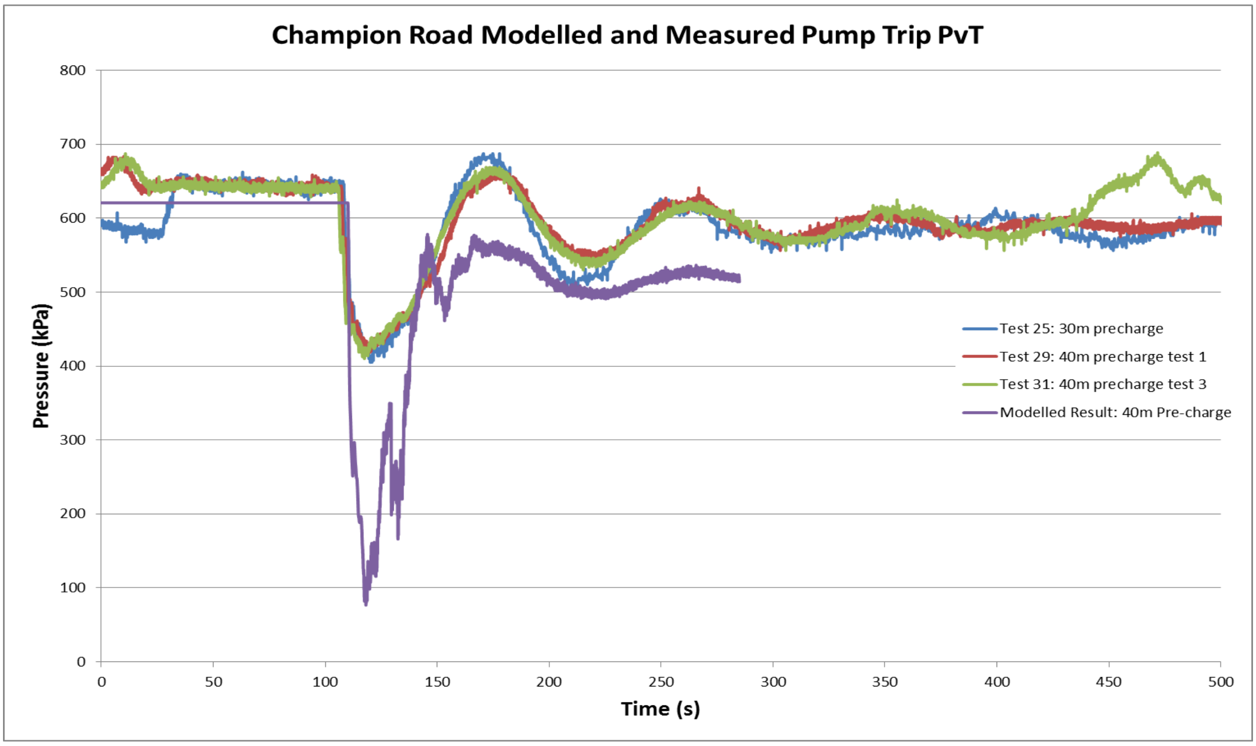


Figure 14: Waimea Zone Mitigated Surge Pressures: Modelled vs. Actual

6 CONCLUSIONS (ARIAL,14)

In conclusion:

- Blending of the two source waters provided the triple benefit of a) improved security of supply, b) dilution as a form of water treatment eliminated the need for expensive, advanced forms of treatment, and c) maximizing consented abstraction limits across the two bore fields
- An investment into understanding the limitations of existing pipe infrastructure gave the project team confidence to re-use potentially fragile AC trunk water mains, thereby reducing capital expenditure. In this case, the maximum working pressure within the existing system was used as boundary conditions for the upgraded system.
- Although the analysis concluded that the AC mains were capable of widthstanding full vacuum under short term conditions, a minimum pressure limit of 0bar was set for both raw and treated mains. Raw mains were kept in the positive range since UV reactors are susceptible to damage under negative pressure conditions.
- The hydraulic model was a critical tool for pump selection, existing pipe pressure analysis and surge identification and mitigation. During the commissioning phase, the hydraulic model was used to help commission the surge vessels.

REFERENCES

New Zealand Water and Wastes Association (NZWWA) "Asbestos Cement Watermain Manual", 2001