BALANCE TANK BYPASS PUMPING SYSTEM AT RICHMOND WATER TREATMENT PLANT

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ABSTRACT

The Richmond Water Treatment Plant is a new domestic water supply treatment plant that serves the town of Richmond, the largest urban settlement in the Tasman district. The plant combines two bore water supplies which feed into it and delivers potable water to two reservoirs systems via a reticulated pipe network. The plant was constructed in 2014-2015 and commissioned in 2015.

A critical element of the treatment plant was a 1500 m^3 tank which balances flows between the supply and demand of the plant. Shortly after commissioning, the tank had to be taken off-line to address some contamination and defect issues.

This paper describes the fast-track design process required and the implementation of an innovative and highly effective solution to the challenge of maintaining potable water supply services during outages of the balance tank.

This resulted in new controls and protection systems added to the infrastructure which creates an automated in-series pumping system that allows the balance tank to be taken out of service for extended periods of time. This can be achieved without any compromise to drinking water quality and quantity. Additionally, the solution had a fully work-shopped risk profile that was acceptable to the client, Tasman District Council.

KEYWORDS

potable water, automation, pumping systems, balance tank, risk profile

1 INTRODUCTION

1.1 PLANT DESCRIPTION

The Richmond Water Treatment Plant (RWTP), herein the "plant", is a key part of a water quality improvement scheme that upgraded the domestic water supply network for the town of Richmond, the largest urban settlement in the Tasman district. The scheme comprised a new 15,400 m^3/day treatment plant and 1,500 m^3 balance tank on a greenfield site, the installation of over 4 km of large buried pipe (up to 450 mm diameter) and upgrades to the two primary bore fields, Richmond and Waimea. The plant was constructed in 2014-2015 and commissioned in 2015.

The scheme design had a unique strategy for blending the two source waters. The Richmond bores had high nitrates and therefore blending with Waimea had the advantage of diluting nitrates to acceptable levels. The blending also allowed the consented abstraction rates from each bore field to be maximised, thus providing more water into the reticulation and ensuring supply to 2030. The plant will have the ability to run of one or both raw water sources, thus giving greater operational flexibility and improving the security of supply.

1.2 BALANCE TANK

The single balance tank was a critical element of the treatment plant. This balances the flows between the supply to, and the demand of, the plant, whilst also providing a hydraulic break in the pumping systems. The water supply and demand pumps had suction head and static head values that could be determined by water levels in tanks.

Shortly after commissioning the plant and during its trial operation period, prior to practical completion of the construction contract, the balance tank had to be taken off-line to address a contamination issue as a result of a defect in the tank roof. While addressing this another defect in the sealant of the tank wall panel joints was discovered. The source of contamination was identified after an internal inspection of the tank and the tank was able to be quickly brought back into service.

A methodology for full sealant repair was prepared and plans were made for implementation within the shortest possible time. The timeframe for repair was estimated to be 6 - 8 weeks. This was a longer period than envisaged for a standard tank outage as originally discussed during project risk and hazard and operability (HAZOP) reviews, which were inclusive of owners, operators and designers.

1.3 BYPASS ARRANGMENT

A balance tank bypass pipe had been added to the plant design during the HAZOP review meeting. This was to facilitate internal inspection of the tank for condition monitoring, and it was also regarded as a contingency measure, up until the time when the future second tank was installed. The tank bypass pipe was buried piping that was installed alongside the balance tank and this included a switch-over valve with tag name VH3051.

At the HAZOP it was decided that the plant automation and controls would not incorporate a bypass pumping mode of operation, as it was envisaged that the risks of balance tank outages could be managed by reservoir drawdown and manual operation of pumps, for any short periods of tank outages.

For a basic piping schematic of the plant, including the balance tank bypass arrangement, refer to Figure 1.

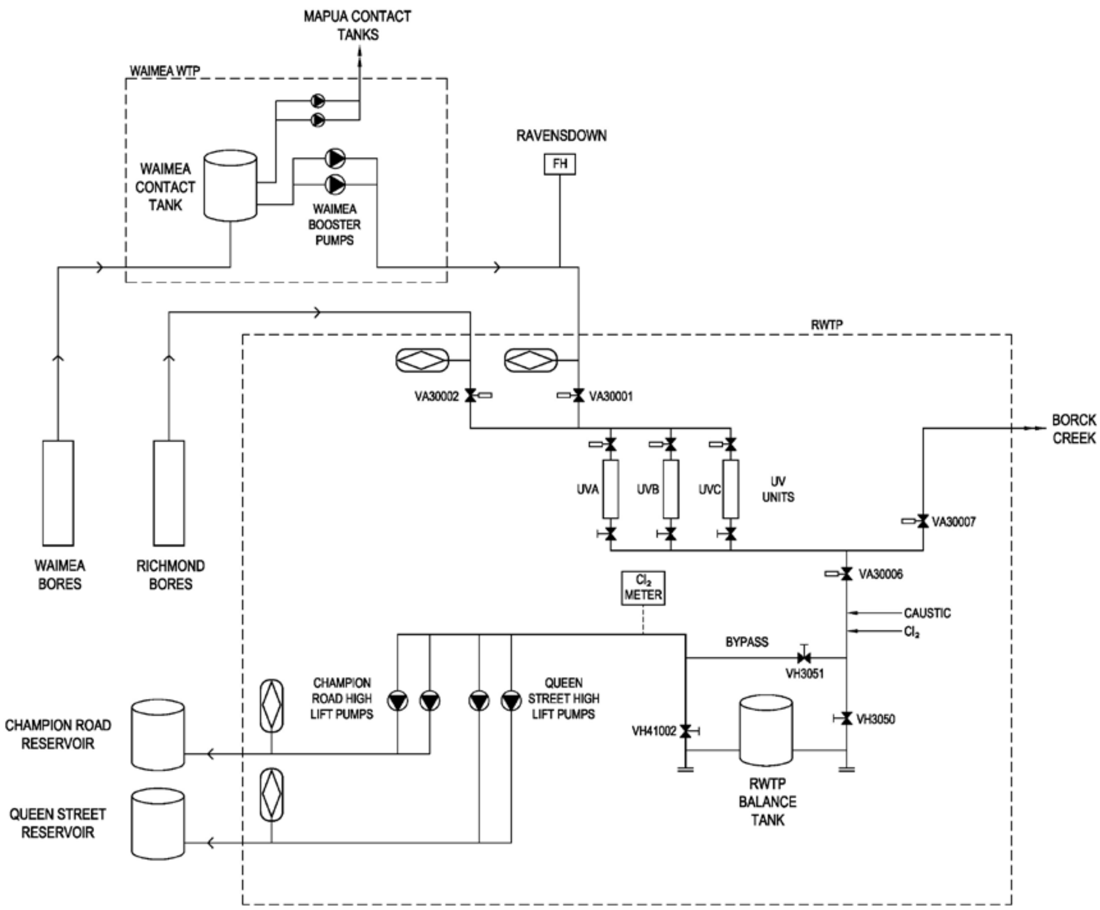


Figure 1: Basic Piping Schematic

2 SYSTEM DESIGN

2.1 BYPASS PUMPING

The design of the bypass pumping system required a strategy and method for maintaining stable and acceptable conditions for the supply and demand pumps, which were required to operate in series during bypass operation.

Without the balance tank, pump start-up and shutdown commands in the existing plant controls would cause imbalance and disturbance in flows. Any large pressure variations at pump suctions and discharges could be harmful to pumps and to the water network pipes. The three pressurised ultraviolet (UV) treatment units at the plant were essential process units in the water treatment process. The UV units were not permitted to sustain negative pressures, i.e. any pressure less than atmospheric pressure.

There had been extensive surge modelling done for the scheme and the mitigation design solution was surge vessels on all inlet and outlet pipes of the plant. The surge vessels had been rigorously tested and commissioned. The hydraulic transient performance of these vessels had been fine-tuned to meet or exceed design expectations, both for the piping networks upstream and downstream of the plant and for the UV units.

2.2 CONTROL STRATEGY

A control strategy for the bypass pumping system was required to handle the unique situation. As the Waimea bores were low in nitrates, this water source was chosen as a sole source for the strategy. The borehole pumps and associated Waimea Water Treatment Plant (Waimea WTP) were known to have sufficient total flow capacity to supply current water demands, by pumping for longer periods each day.

This meant that the controls for two pumps in one location, at Waimea WTP, would need to be modified in order to make the strategy simpler and avoid unnecessary flow and pressure disturbances from pump changeovers between duty and duty/assist operation. These pumps had recently been commissioned and were found to be operating well together, as a duty/assist pair, for higher flows.

The strategy called for a controls functional design that focused primarily on the direct hydraulic coupling and interactions of Waimea and Richmond pumps when the balance tank bypass was put into service.

It was also important that the controls maintain stability in the performance of the RWTP which was more responsive to changes in water demand driven by water levels in the reservoirs. In view of the critical nature of the new controls and the long time period over which they were needed to operate, manual control and operator intervention were to be minimised. It was decided that a separate control mode would be added to the RWTP controls, which were fully automated. This was called the balance tank bypass mode.

2.3 FUNCTIONAL DESCRIPTION

The Functional Description was developed during the design phase of the bypass pumping system. All those involved in the design and implementation of the Richmond WTP working collaboratively in its development. There was a need to "fast-track" the design and implementation of the new mode of operation.

This began immediately after the control strategy was agreed to by all parties. A draft functional design specification was prepared for the main construction contractor to review. This was fully discussed and reviewed and then developed into a completed functional description, after more in-depth discussions and site-based workshop with the lead designer and principal technician of the electrical sub-contractor. The electrical sub-contractor had completed control systems integration for the Richmond water scheme in the past and was highly knowledgeable of its operational needs and vulnerabilities. The new plant was configured to include the master controllers and communications hardware for the whole scheme, via telemetry links.

The operation of the balance tank bypass mode at RWTP involved in-series pumping of Waimea WTP Raw Water (RW) Booster Pumps and RWTP High Lift (HL) Pumps, in one continuous flow pathway from the Waimea break tank to the low level reservoirs (at Queen St and Champion Rd). During the tank bypass operation there was no automated operation of Richmond bore pumps.

The purpose of the controls Functional Description (FD) was to describe automatic controls for a mode of operation that allows the balance tank to be taken off line for an extended period by utilising the tank bypass piping. In this mode only the Waimea RW Booster pumps provided raw water to the RWTP, and the Richmond bores were kept off-line.

During this mode, both RWTP HL pump sets (Queen St and Champion Rd) are able to operate together, unless the operator decides to take one of the RWTP HL pump sets out of operation. If a flow is detected at the Ravensdown hydrant the RWTP will shut down as was previously programmed. Other interlocks were retained, added and disabled for this mode of operation, as stated in the FD.

Prior to starting-up the bypass operation, the Consenting Authority was contacted to notify them of the need for occasional discharges of excess or non-compliant water from the “station to waste” line to Borck Creek, during operation of the bypass. Critical industrial users including the Fire Service were also notified that RWTP will be operating under a tank maintenance operating scenario, but with no change to hydrant operation.

A low level of input from operational staff is required when in balance tank bypass mode. Operator attendance is required at start-up and shutdown, and may also need to be in attendance and on call at other times, to monitor and respond as necessary to reservoir, pump, plant and piping system operating conditions. The overall scheme water supply and demand balance needed to be forecasted, monitored and managed, to account for any plant constraints or seasonal effects during the period of time required for bypassing the balance tank.

The FD incorporates ‘friction-compensation’ control of the Waimea RW Booster pumps, which provides for a hydraulic profile to the RWTP similar to that under normal operation of Waimea bore water feed only to RWTP. This effectively replicates the function of the balance tank as a pressure break and suction tank for the RWTP HL pumps, without the buffer volume function of the balance tank.

The controls were based on having a variable set point pressure control of Waimea RW Booster pump speed, dependent on flow rate, using an algorithm within the controls program. The algorithm is in the form of a theoretical parabolic equation for pipe friction that can be used to approximate turbulent hydraulic systems. The equation for the algorithm was $Psp = 0.0047(Q^2) + 73.5$, where Q is the Waimea WTP discharge flow rate (in l/s units) and Psp is a pressure set point (in kPa units), to be compared against Waimea WTP discharge pressure.

For a chart of Waimea WTP discharge pressure versus flow refer Figure 2.

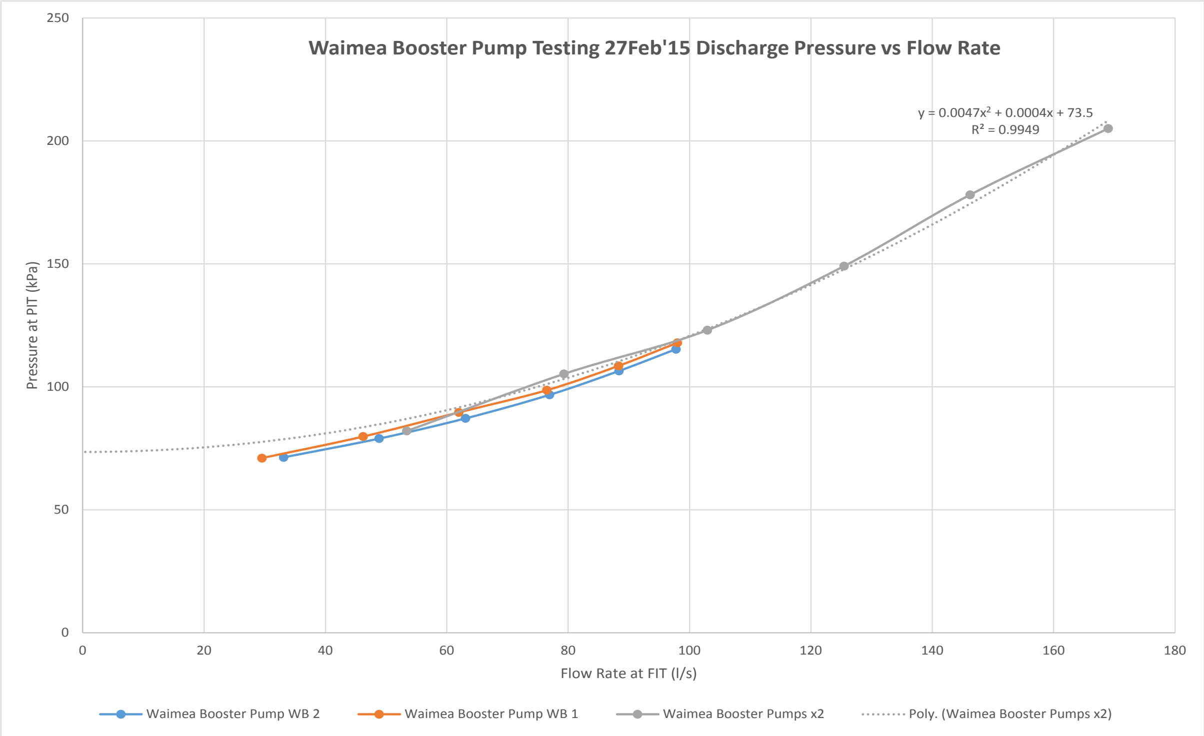


Figure 2: Chart of Waimea WTP Discharge Pressure versus Flow

Figure 2 shows the equation of a best-fit 2nd order polynomial curve analysis of test results from pump testing. The middle term, a linear equation term, in the (x-y) trend equation displayed on the chart was omitted from the FD because it was insignificant. This make the equation quadratic, matching the theory mentioned above. The source data was from testing of the Waimea RW Booster Pumps done during testing and commissioning of the RWTP, refer Figures 3 and 4.

The controls also have a function that keeps two Waimea RW pumps (Duty and Assist pumps) operating together at all times. This was to minimise transient instabilities in the bypass pumping system. There were others features of the controls that helped minimise disturbances during the start-up of the bypass operation. These included the automation of the “station to waste” valve VA30007 to pulse open and close under certain conditions, either at bypass mode start-up or to mitigate flow imbalances during bypass mode operation. Another feature of the controls, which was added during testing and commissioning, was to restart the HL pumps during the speed reduction phase of a stoppage when the pump suction pressure was restored.

There were a number of interlocks and other protection measures built into the FD. Some of these were a direct result of the detailed controls review workshop with the electrical sub-contractor. The electrical sub-contractor’s in-depth knowledge and familiarity with the specifics of the RWTP controls programming greatly assisted and enhanced the FD. The electrical sub-contractor prepared a preliminary sequential function list for review by the lead designer, which was a design development tool to align the FD to the controls programming work which was to follow after the final revision of the FD.

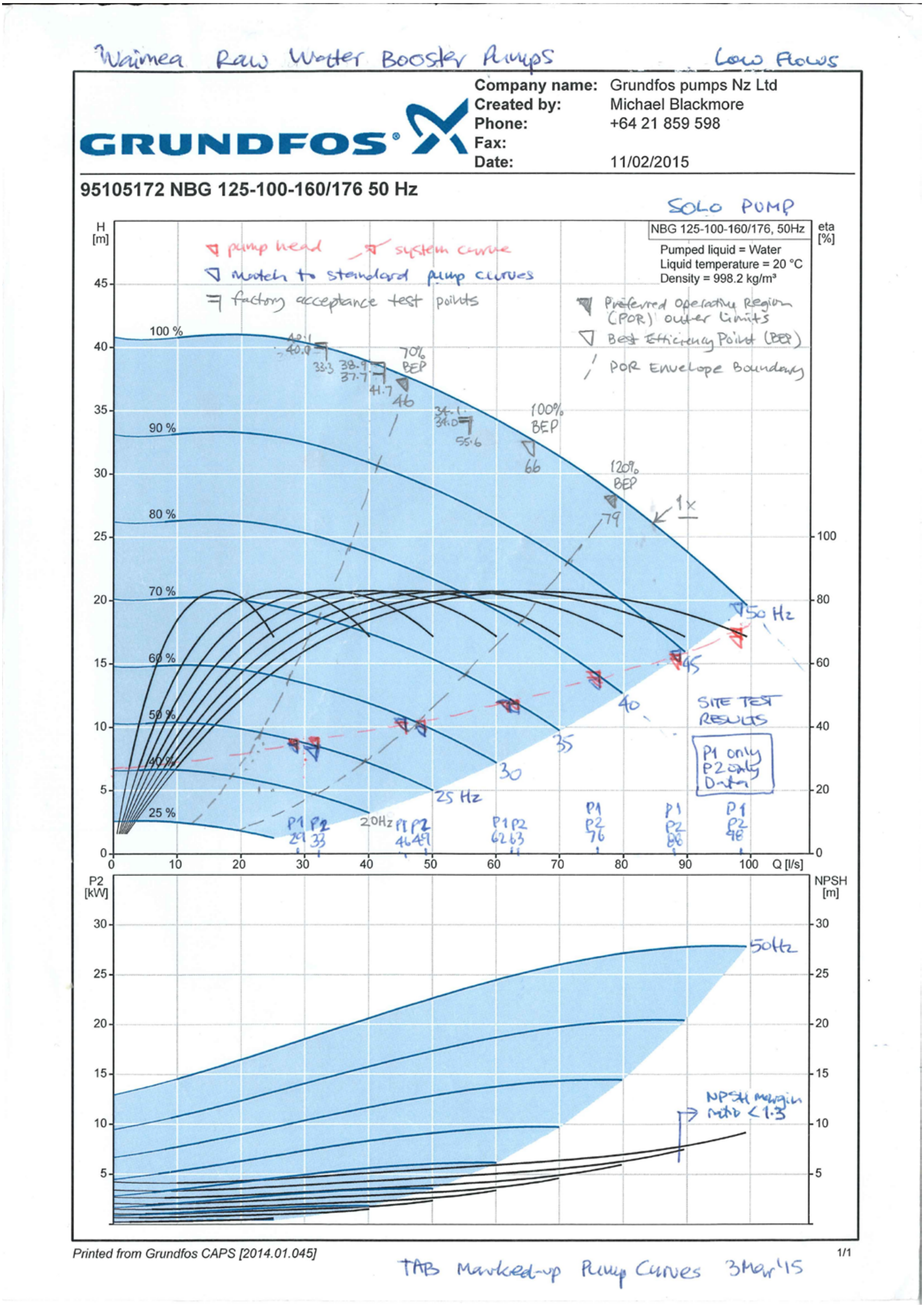


Figure 3: Waimea RW Booster Pumps Solo Performance Test Curves

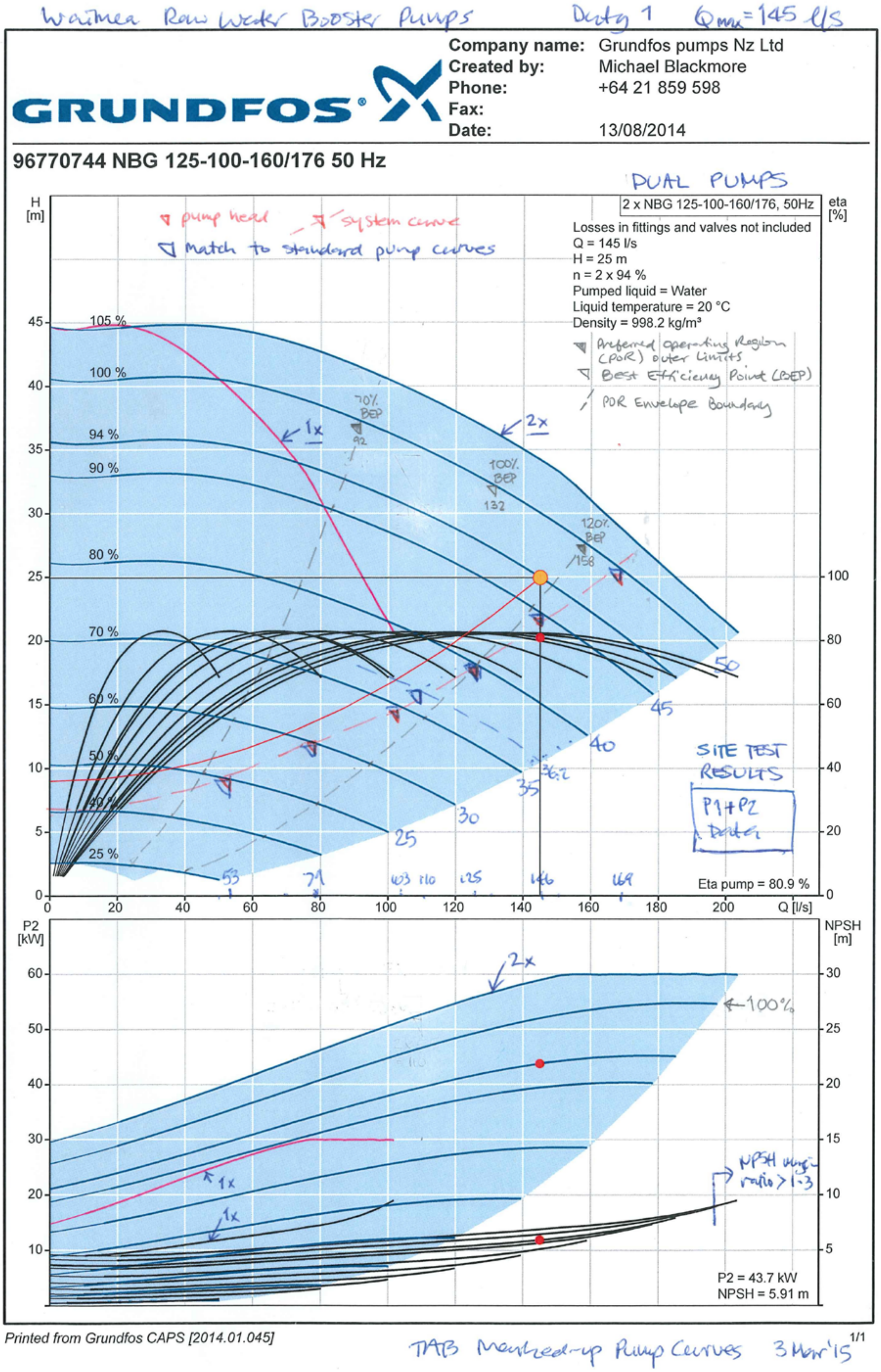


Figure 4: Waimea RW Booster Pumps Dual Performance Test Curves

3 IMPLEMENTATION

3.1 RISK WORKSHOP

Before finalising the design and commencing with implementation of balance tank repair and the bypass mode of operation, the risks were identified, assessed and analysed and managed in a highly structured way. Firstly, a risk matrix was prepared and sent to all those involved, then a risk workshop held. The objective of the workshop was to present the design and to discuss, amend, define and agree the risks and then determine their causes, effects, probability, impact, owner, expiry date and the mitigation strategies and actions required.

For a list of the risks that were identified and managed at the risk workshop, refer to Table 1.

Table 1: List of Risks Identified and Managed at the Risk Workshop

No.	Risk	Causes	Effect
1	Richmond demand not met	Bypass fails while tank being repaired and out of service	Loss of water supply to Richmond town
2	Richmond demand not met	Tank sealant curing process takes longer than envisaged	Greater reliance on bypass, compromise to water supply
3	Richmond demand not met	Waimea Water supply failure. For example, burst main, Waimea booster pump failure, bore failure	Loss of water supply to Richmond WTP and town
4	Richmond demand not met	Limitations in bypass operation (Flow balancing) limit RWTP production capacity	Demands from Richmond town cannot be met
5	Richmond demand not met	Failure of two UV Units	Bypass mode may not be able to operate at full flow with just 1 reactor
6	Richmond demand not met	UVs start and stop more than 4 times a day, because plant shutting down at quiet times due to lack of balance tank buffering	UVs going out of service. UV reactor guarantees affected.
7	Richmond demand not met	Sustained water quality event	Water supply to Richmond compromised
8	Richmond demand not met	Communications failure	Lose control of pumps and valves. No supply to Richmond
9	Richmond demand not met	Power failure	Loss control of pumps and valves. No supply to Richmond
10	Richmond demand not met	Ravensdown Hydrant is opened	Firefighting water become a priority. No flow to HL pumps. Not able to feed Richmond town demand.
11	Equipment damage	Bypass reliant on accurate control of double (in-series) pumping. This can sometimes cause instances of transient flow instability within pumps.	Possible effects include additional pump wear, shaft seal leakage, and premature replacement of wearing parts.
12	Equipment damage	Damage to UV reactors during bypass pumping as a result of high / low pressures.	Costly repairs to UV units, and inability to treat UV units to required DWS standard
13	Equipment damage	Negative pressure on UV units when station to waste is triggered from a water quality event, HL pumps slow down slower than the rest of the plant stopping water (via valves).	Damage to UV units
14	Equipment damage	Too much flow/pressure in Waimea line to maintain small drops in pressure in line with two pumps during periods of no flow to RWTP.	Booster pumps hunting and/or pipe breaks
15	Equipment damage	Air accumulation in piping at high point in piping upstream of high Lift pumps	Waimea pumps run at high speed. HL pumps stop on low suction pressure or (if enabled) dry-run protection function in drive.
16	Water Quality Compromised	Non-compliant water quality from Waimea over relatively long period of time (e.g., flood of Waimea river basin)	Either 1) No water supply to Richmond town (discharge via Station to Waste) or 2) water delivered to town not

		This is a result of only having one raw water supply into plant, whereas normally we also have Richmond bores.	compliant with DWS.
17	Water Quality Compromised	Caustic overdoses (without the balance tank there is no buffer)	Public health risk - high caustic can cause burns.
18	Water Quality Compromised	Chlorine is required to be dosed at the plant	Increased potential to over/under dose the network without Balance tank as buffer (and loss of contact time without balance tank)
19	Unsatisfactory performance of bypass	HL pumps starved of flow during testing and/or bypass operation.	Low pump suction pressure, air is drawn into pump, cavitation and pump damage
20	Unsatisfactory performance of bypass	Waimea pump control by friction compensation function does not perform well, e.g. due to process/control dynamics	Extended testing / commissioning phase, delays to tank repairs
21	Unsatisfactory performance of bypass	Variable performance due to differences in HL pump curves across four different model pumps	Delays to completion of testing due to difficulties with tuning of controls. May need to exclude a pump from bypass mode.
22	Tank repair defect	Tank interior contaminated by repair operation	Contaminated water supply and/or protracted reliance on bypass
23	Scour of Borck Creek	Flow to Borck Creek	Scour sedimentation. Effect on Downers contract

3.2 CONTINGENCY PLAN

One of the outcomes of the risk workshop was an action to prepare a contingency plan.

The plan was prepared jointly by the designers, constructors and representatives of Tasman District Council. The following summarises the items covered of the contingency plan. Procedures were written for each items.

Loss of Raw Water Supply to RWTP

- Alternative Water Supply – options included: conserve water notices, turn on Appleby bore, connect Richmond bores directly to distribution network, use Nelson water, Richmond bores supply to reinstated balance tank (partly-repaired)

- Waimea Bores – options included: turn on Waimea emergency bores

- Waimea WTP – options included: replace a failed Waimea booster pump with spare pump held in stock

- Pipelines – options included: repair broken pipes using spare pipes held in stock.

Inability to Meet Demand

- High Lift Pumps – options included: replace seals and/or bearings on a failed standby pump, use single duty pump if VSD failure occurs on a standby pump

- Demand Greater Than Supply – options included: augment with an alternative supply (as listed above)

- Pipelines – options included: repair leaking pipes using spare pipes held in stock

- Richmond Bores – options included: manually operate one or two Richmond bores in addition to the automatic bypass mode control of Waimea RW booster pumps, connect Richmond bores directly to Richmond Reservoir network, Richmond bores supply to reinstated balance tank (partly-repaired).

Poor Water Quality and/or UV Treatment Failure

- Poor Raw Water Quality – options included: issue boil water notice, chlorinate supply at RWTP, chlorinate supply at Waimea WTP, disable station-to-waste functionality (with mitigation employed)

- UV Reactors – options included: reduce number of start/stops per day, rapid repair of UV units or remove lamps from UV units (with mitigation employed).

Balance Tank Required

- Balance tank required at short notice – options included: reinstate balance tank (partly-repaired).

Power/Communications Failure

- Waimea WTP/Bores – options included: use backup generator, use alternative water source

- Richmond WTP – options included: use backup generator at Waimea, use alternative water source

- Both Waimea and Richmond WTP – options included: use alternative water source

- Other – options included: keep UV units operating to avoid stoppage from the protection interlock that prevents more than 4 starts per day, by overflowing reservoirs or pumping excess to other water schemes, storage systems or to users who can overflow excess volumes to waste.

3.3 TESTING AND COMMISSIONING

At both the pre-commissioning and commissioning phases of the work a step-by-step series of functional and operational tests were proposed, revised and agreed to jointly by lead designer and lead electrical technician. In addition to functional tests, physical tests were also done at the pre-commissioning phase. These included tests on the one only additional instrument, a pressure transmitter (with integral pressure switch) at the pump suction manifold of reticulation feed pumps (High-Lift pumps) at Richmond WTP. Testing of an existing control valve VA30006, for its opening position under various scenarios, was also done at pre-commissioning phase.

The following outlines the methodology used for testing and commissioning the bypass control system.

1. Install and function-test devices that are required for protection of plant

2. Pre-program control functions that cannot be simulated by manual testing

3. Function-testing of discrete steps of automation prior to manual operation testing

4. Manual operation of individual operating states to evaluate performance and settings

5. Testing of dynamic responses of pre-programmed functions to evaluate performance

6. Trialling and tuning of various control parameters used in pre-programmed functions

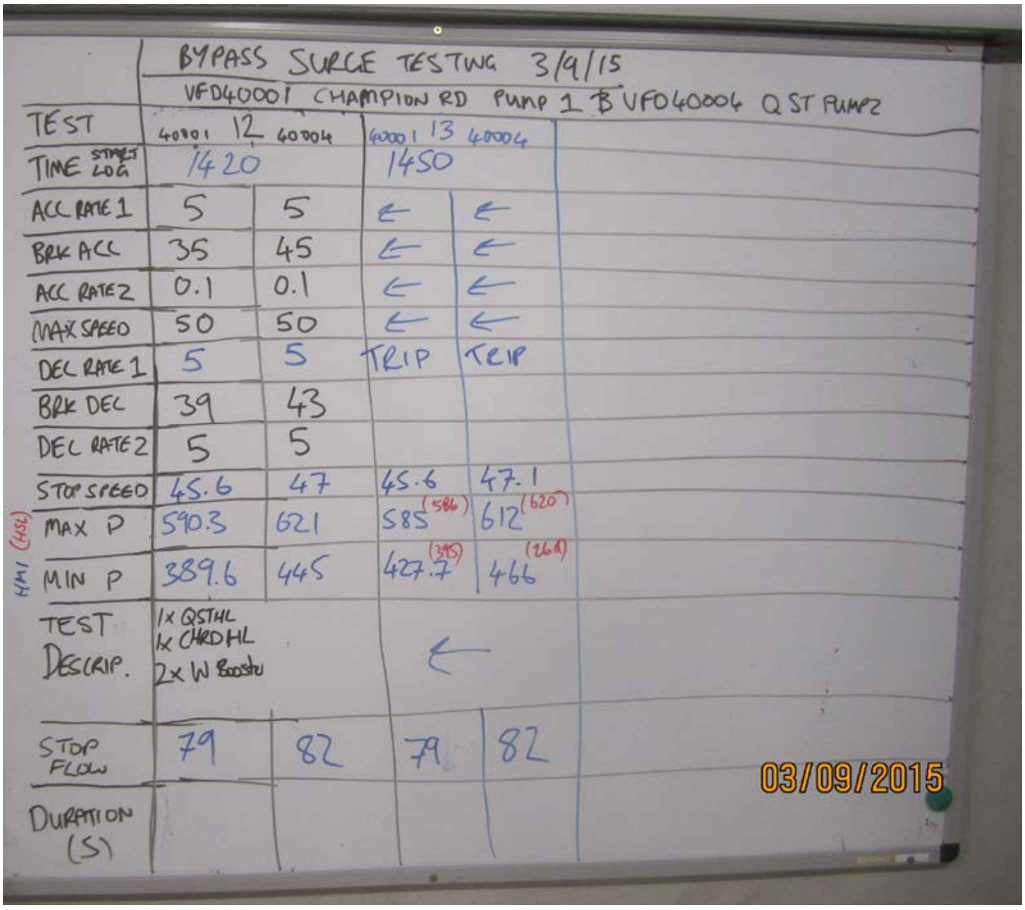
7. Make revisions and adjust the settings in the controls Functional Description (FD)

8. Programming a fully-automated sequence and integrating it into the control system

9. Commissioning and performance monitoring of bypass mode fully-automated controls.

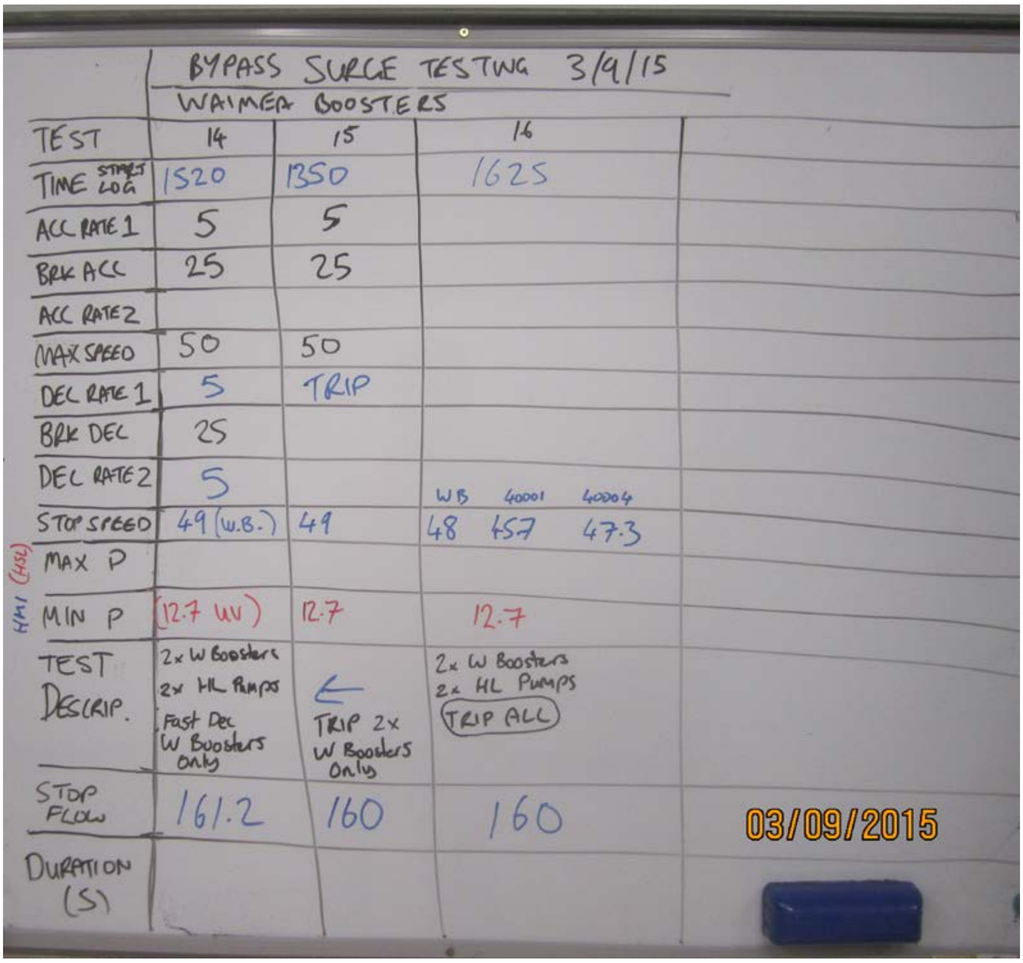
The commissioning of the bypass pumping system was undertaken by the lead electrical technician, with full-time supervision and observation and review by the lead designer and the representative of the Engineer to the Contract for the RWTP construction contract. The representative of the Engineer to Contract planned and managed all site monitoring activities and was a member of the design development team for the bypass pumping system. The commissioning went according to plan and the bypass control mode was proven to meet or exceed all stated objectives. The remote control commands of RWTP as the master to Waimea WTP operated together very satisfactory and the newly integrated scheme as a whole exceeded all expectations. After a trial operation and review period, there were no changes to the FD and only fine tuning of the control settings.

For an illustration of the method used for managing and documenting the testing and commissioning, refer to Photographs 1 and 2, as examples of whiteboard note taking done at the RWTP control room, during surge testing.



Photograph 1: Whiteboard Note Taking During Surge Testing

The variable frequency drives, as installed on all pumps, were used to make small incremental changes to rotational speed acceleration and deceleration rates, from slow rates to rapid rates, moving closer to the worst-case power outage scenario of very rapid deceleration (limited only by the rotational inertia of pump and motor).



Photograph 2: Whiteboard Note Taking at Conclusion of Surge Testing

The final surge test (Test 16) was a real-time test of the ultimate worst-case surge scenario, a simulated regional power outage. The test involved the power being switched off simultaneously at both Waimea RW Booster pumps (operating duty/assist) and the Queen St and Champion Rd High Lift duty pumps, while all pumps were operating at their full capacity. This was a sudden stoppage of the entire in-series pumping system at maximum pumping energy, imparting a large hydraulic motive force over the entire piping network. This was the ultimate hydraulic transient performance test for the bypass pumping system and the response of surge attenuation vessels at inlets/outlets of RWTP and an air/vacuum release valve that was installed at the UV discharge piping.

A pressure transmitter with a high frequency logger was installed at the UV inlet manifold for all surge testing, as this was the most critical equipment to protect from negative pressures (i.e. pressures less than atmospheric). For a plot of the UV pressure response over time elapsed, from the start of Test 16, refer Figure 5.

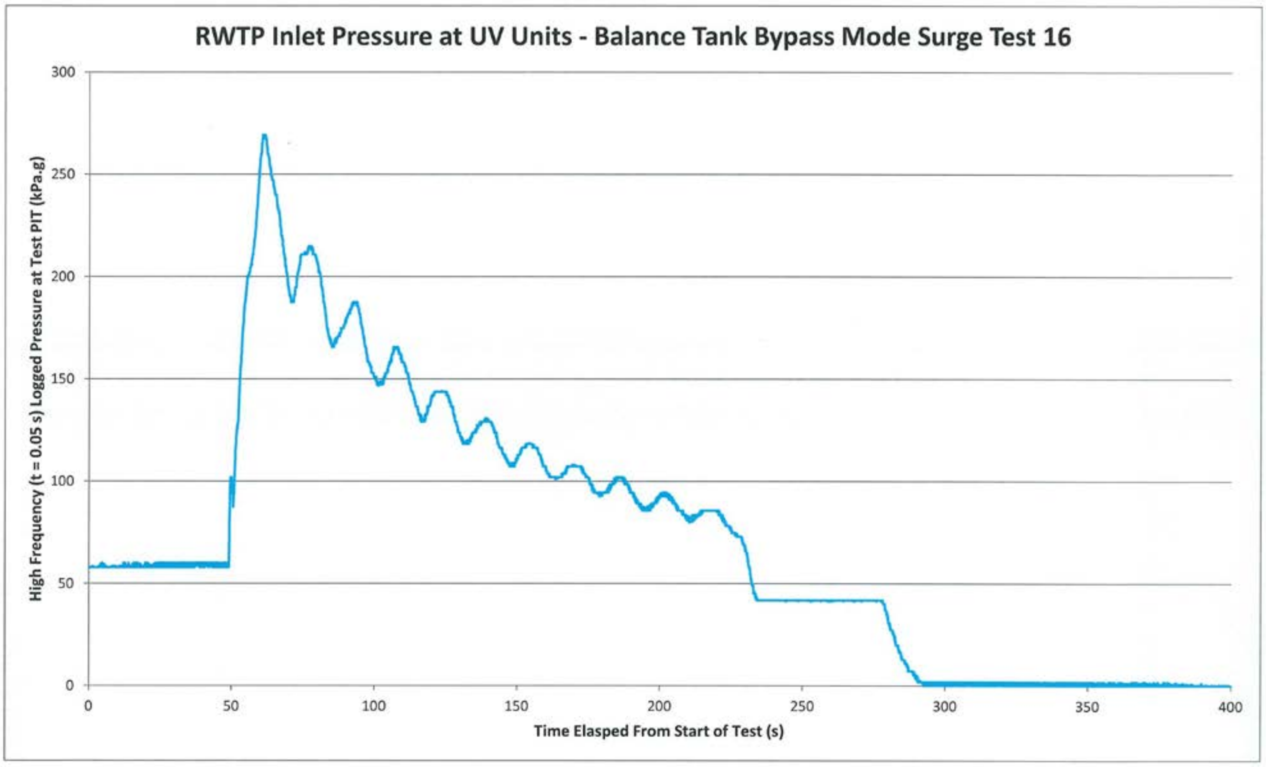


Figure 5: Chart of Surge Test 16 UV Units Inlet Pressure Results

3.4 OPERATIONAL RESULTS

The bypass pumping system was found to be a highly reliable and stable mode of operation, meeting all of the objectives and requirements, as defined and agreed by all parties. There were no disturbances, interruptions or reduction in quality, or level of service, experienced by residents, commercial and industrial users of the water in the greater Richmond area. The risks in the risk matrix did not eventuate and the items in the contingency plan did not need to be implemented. The balance tank pumping system required no operator supervision or intervention and the treatment plant systems operated normally and successfully requiring UV-only sterilization.

The transitions of start-up and shutdown were seamless. The bypass pumping system operated continuously over a period of several weeks more than the originally estimated tank outage period of 6 - 8 weeks. A second outage was instigated about 6 months later, for tank internal inspection, and it was decided to use the bypass pumping mode of automatic control in preference to putting the RWTP out of service state and planning and relying on a managed drawdown of reservoirs.

The bypass mode made tank inspections a non-critical event, in terms of the period of outage not being limited in its duration, and thus providing considerably more operational flexibility.

4 CONCLUSIONS

The balance tank bypass pumping system as described above was successful in achieving all goals and objectives and met all operational requirements.

The highly skilled, collaborative and innovative work done by experienced project leaders, specialist engineers and technicians were the most significant factors in its successful completion.

It is concluded that:

1) Balance tank bypass pumping systems involving supply and reticulation pumps operating in series can have automated controls that are stable, safe and secure

2) Friction compensation control of pumps that supply water over long distances can be employed where high-speed long-range communication is not available

3) Risk assessment and contingency, testing and commissioning plans are enhanced by being inclusive of project managers, designers, constructors and operators

4) Collaborative and interactive teamwork by engineers and constructors was a key factor in the successful fast-track design and implementation of the control system.

ACKNOWLEDGEMENTS

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