# DIGITAL PUMP MONITORING: STRIVING FOR PREVENTATIVE MAINTENANCE

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## ABSTRACT

The digitalisation revolution is driving innovation in many industries from mobility (think Uber, Lime scooters) to healthcare to goods distribution and information technology. Mobile internet, cloud technology, processing power, data analytics, artificial intelligence and the Internet of Things are helping optimise water and wastewater management with the development of data analytics for continuous monitoring of pump performance and the utility's water network as a whole. Historical records are just snapshots in time; a lot of important information can be missed. Whereas continuous monitoring, which is 'daylighting' data which has been unseen perhaps lost in misplaced historical records, gives complete data over all operating conditions and longer periods of time.

Many councils are striving for preventative maintenance over reactive maintenance but are often constrained by limited resources. Councils are looking at how they can obtain value and efficiencies from using their data to get the most out of their assets through preventative maintenance, while achieving their sustainability targets. Continuous monitoring of pump performance looks set to disrupt the market for one-off 'snapshot' pump performance testing services.

Most electricity consumed by water utilities is required for pumping water through the various stages of extraction, treatment, and final distribution to consumers. The reality is that many pumps in service run at efficiencies lower than their manufactured state and outside peak efficiencies. If all councils ran their pumps more efficiently, the world can save significant amounts of energy consumption, money and greenhouse gas emissions.

This paper presents the results from a proof on concept pilot for continuous monitoring of pump performance, water network balance and water infrastructure leakage index using SCADA data readings in Info360 software by Innovyze.

Additionally, a pump performance benchmarking database will be introduced which was developed using historical thermodynamic pump performance test data from 66 pumps from three New Zealand water utilities.

## KEYWORDS

**Pumping, energy efficiency, scada, data analytics, continuous monitoring, asset management, preventative maintenance, disruptive technology, skills disrupted, pump performance benchmarking, pump performance testing, thermodynamic method**

**PRESENTER PROFILES**

James Curtis has over eight years' work experience as a mechanical engineer working on the design and manufacture of water & wastewater process equipment and the design and build of meat by-product (meat rendering) processing plants and machines. More recently James has been designing large storage tanks for dairy farm effluent, agriculture irrigation and water & wastewater treatment plants. At Cardno James has been the pump performance testing lead and has prepared engineering designs for various water & wastewater infrastructure upgrades.

Hywel Lewis has over 20 years' experience relating to water resources situation assessments, river basin studies, stormwater management plans, hydraulic runoff modelling (stormwater and overland flows) and wastewater modelling and integrated catchment modelling. Hywel has significant experience in calibrating wastewater models in New Zealand, managing flow surveys, GIS analysis and data management aspects of major wastewater drainage area studies in the UK and New Zealand.

# 1 INTRODUCTION

## 1.1 CONTINUOUS MONITORING OF PUMP PERFORMANCE

Pump performance testing uses calculated pump operating efficiencies to provide a baseline and ongoing measure of pump efficiency at the pump station's typical operating conditions and helps with developing pump refurbishment and renewal programs. Cardno has been providing pump performance testing services in New Zealand using thermodynamic and conventional techniques. The standard method is to test each pump independently at an operating frequency of 50Hz. Pump flow rate, discharge pressure, suction pressure and motor power are recorded at the same time, at different flow rate and pressure duty points by throttling individual pump discharge valves. The conventional technique of pump performance testing relies on using existing pump station instrumentation including the magnetic flow meter (if available) while the thermodynamic technique provides independent calibrated instruments including individual pump flow and power measurement.

Cardno estimates that savings of up to 8% on energy costs may be achieved by responding to significant drops in pump efficiency via. targeted pump refurbishment. And improving pump operation and sequencing by running the most efficient combination of pumps at the appropriate speeds is expected to yield savings of up to 5% on energy costs plus the added benefit of extended pump life. The closer a pump is operated to its best efficiency point, the lower are the forces acting on the pump bearing and seals thus maximising service life. Pump performance testing also provides accurate data for calibrating hydraulic water and wastewater network models. Targeting pump performance testing on the pumps with the highest energy use (motor operating power multiplied by run hours) and/or any pumps where known performance issues are occurring is the recommended starting point.

Wellington Water were looking at ways they could use and share the time series data which they collect from the water and wastewater network more effectively and proposed an investigation into how Info360 software by Innovyze could facilitate continuous monitoring of pump performance using their pump station SCADA sensor data which was already being collected. They also wanted to see whether a water network balance and water infrastructure leakage index calculation could be completed in Info360 using their SCADA data. It was believed that Info360 could help make sense of the SCADA data by bringing it 'under one roof' for analysis. The following section discusses the Info360 proof of concept pilot which Cardno was engaged to help with.

## 1.2 PUMP PERFORMANCE BENCHMARKING DATABASE

The Water Research Foundation (WRF) published a report in 2017 titled Performance Benchmarking of Pumps and Pumping Systems for Drinking Water Utilities (Badruzzaman et al., 2017), which presented their study on developing a pump performance benchmarking database using pump station SCADA sensor data. The WRF's aim was to develop the database for utilities to gain additional assurance or validation that their pumps are performing as well as the pumps in peer utilities. And benchmarking values could be used as guidance for screening inefficient pumping systems for further assessment of energy performance improvement opportunities. The WRF envisioned that the benchmarking database would be continuously updated with additional pump data to allow the users to develop higher confidence in the understanding of the impacts of several important factors such as pump combination selection, pump maintenance and using variable speed drives (VSDs) on pump energy consumption.

The WRF used readings from pump station SCADA sensors and data from monthly energy bills for the pump performance calculations. Eighteen water utilities provided data for the study including Wellington Water, Hunter Water and Unitywater; a total of 177 pumps were studied. Unfortunately, the WRF study was hindered by the accessibility of the SCADA sensor data and inaccurate and unreliable instrumentation. The following section discusses the development of a new pump performance benchmarking database using historical thermodynamic pump performance test data from 66 pumps from three New Zealand water utilities. Cardno believes that the thermodynamic pump performance testing data is of superior quality compared to the SCADA data in terms of its accessibility and accuracy.

# 2 DISCUSSION

## 2.1 CONTINUOUS MONITORING OF PUMP PERFORMANCE

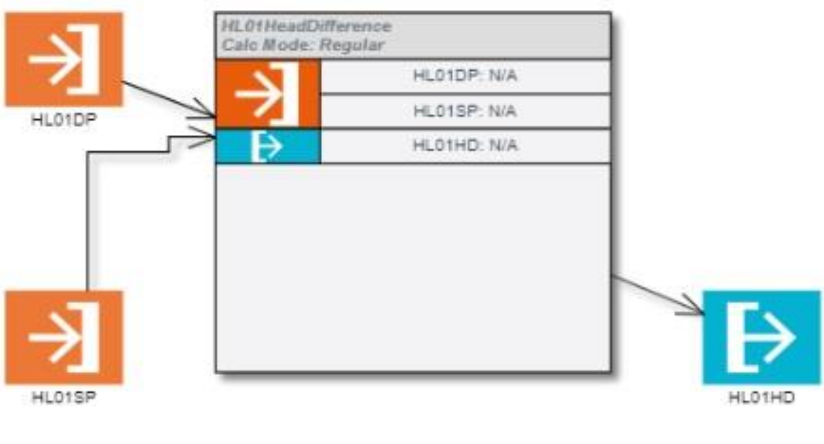
The scope of the Info360 software pilot was to try out Info360's continuous monitoring of pump performance feature which was expected to be able to plot live operating pump performance data onto manufacturer's pump curves. Info360's BizBlock and charting functionality together with available flow rate, motor power and suction and discharge pressure SCADA data was said to provide desired outcome. Wellington Water usually carried-out regular snapshot pump performance testing using the thermodynamic or conventional method. The results from the pilot could be compared with the pump performance testing results. A water network balance and water infrastructure leakage index calculation was also to be attempted using SCADA data in Info360.

One of Wellington Water's main attractions with Info360 was the idea that all the calculations could be done on the software using the SCADA data directly which would avoid using Excel spreadsheets. Info360 'sits on top' of an existing SCADA system receiving data inputs already being collected from the existing SCADA sensors. Info360 was expected to provide the capacity for uploading thousands of sensors and offered an holistic approach where multiple assets could be analysis together e.g. reservoir levels upstream vs. pump capacity downstream. The antiquated Excel spreadsheets and macros, which were labour intensive and prone to 'crashing' from overloading, could be eliminated thus freeing up time to spend on data analytics.

In order to keep the pilot simple, all SCADA data used for the continuous monitoring of pump performance was limited to historical SCADA data which was downloaded into CSV data files. The CSV data files were uploaded as "updatable sensors" which could then be used in the same way live SCADA data would be. Live SCADA data was used for the water network balance and water infrastructure leakage index calculations however.

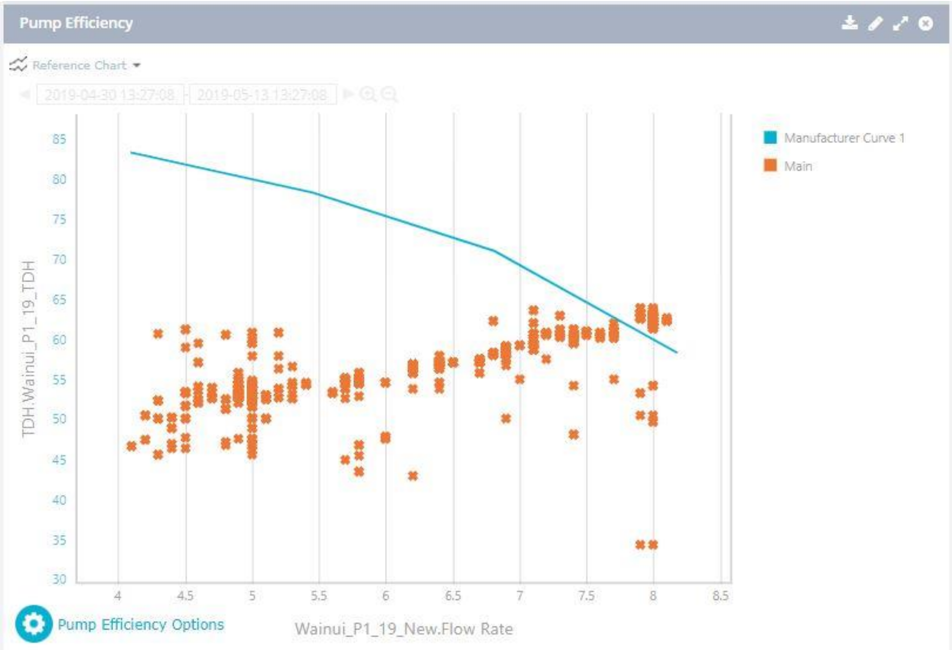
Info360's Pump Efficiency Chart sub-tab allows the selection of imported data and plots typical pump curves such as head difference vs. flow rate, pump efficiency vs. flow rate and shaft power vs. flow rate. Other customised pump efficiency calculations, for example the Water Research Foundation's (WRF) PPI_TDH, can also be plotted. Typically the Pump Efficiency chart's x axis data is selected as the pump flow rate. The Pump Efficiency calculations were completed using BizBlocks, which allows new 'sensors' to be created calculated from existing ones. For example, the head difference across the pump is created as a new sensor by calculating the difference between the discharge pressure and suction pressure as shown in Figure 1.

*Figure 1: Typical Pump Efficiency Calculation BizBlock*



The Head Difference vs. Flow Rate chart with the manufacturer's pump data is shown in Figure 2.

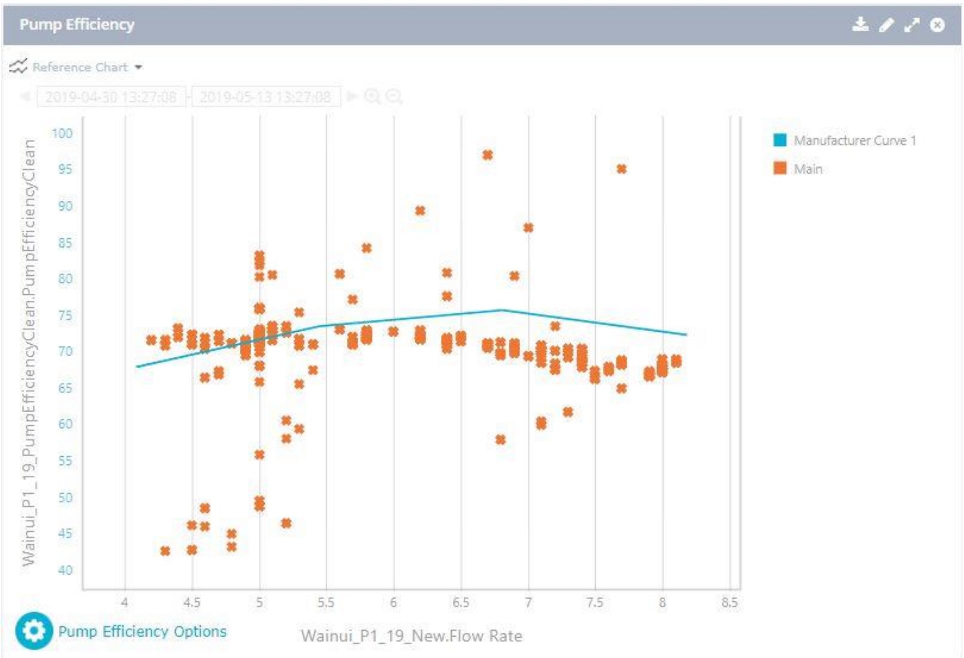
*Figure 2: Head Difference vs. Flow Rate chart*




The manufacturer's data was entered manually onto the Pump Efficiency chart. In this case the manufacturer's pump data was adjusted (using the pump infinity laws) for the actual pump operating speed found in the SCADA data. In this case the pump was running at 40 Hz rather than 50 Hz which the standard manufacturer's pump data is based on.

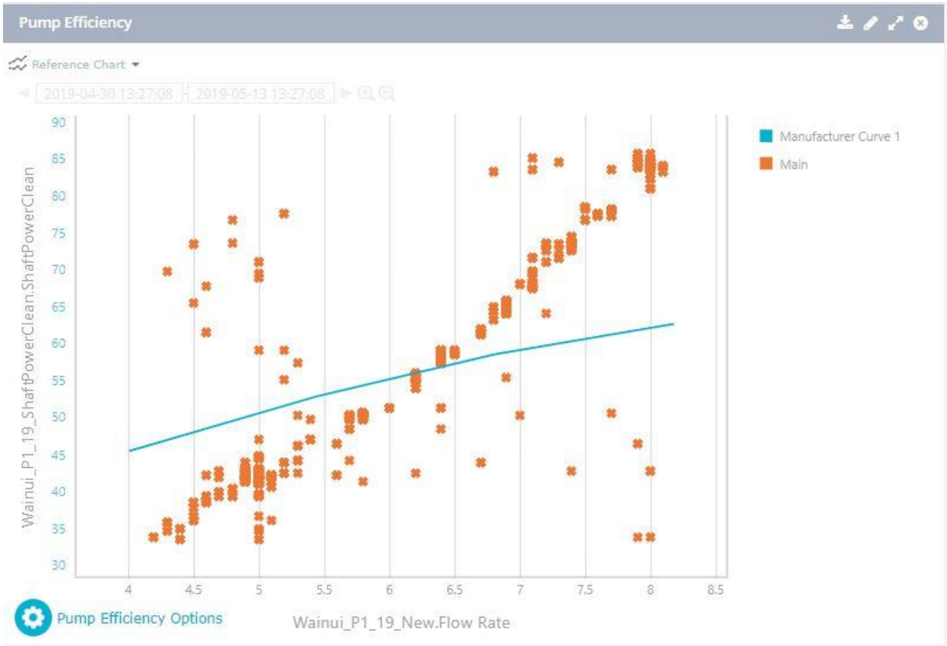
The newly created sensors from the BizBlocks could be then used to calculate other new sensors in another BizBlock. For example the head difference was used along with motor power and flow rate to calculate the pump efficiency. The Pump Efficiency vs. Flow Rate chart with the manufacturer's pump data is shown in Figure 3.

*Figure 3: Pump Efficiency vs. Flow Rate chart*



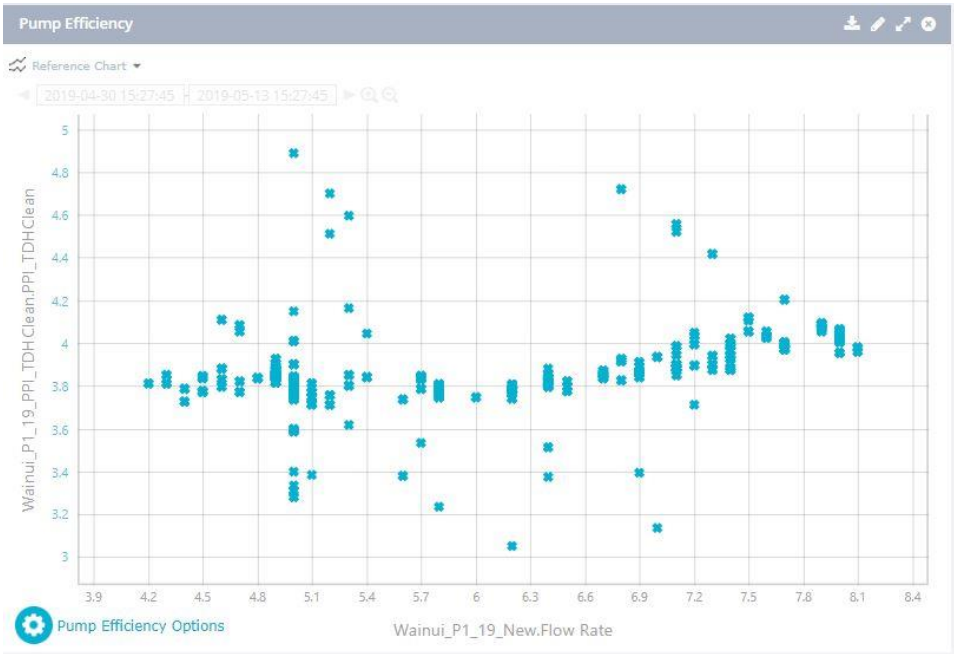
The Shaft Power vs. Flow Rate chart with the manufacturer's pump data is shown in Figure 4.

*Figure 4: Shaft Power vs. Flow Rate chart*



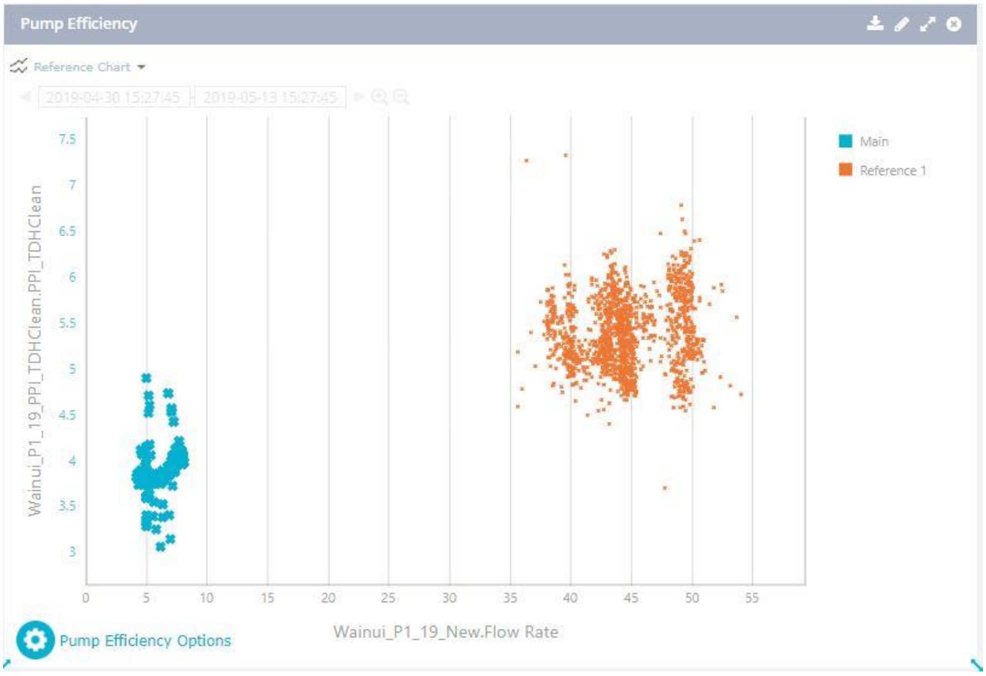

The WRF PPI_TDH vs. Flow Rate chart is shown in Figure 5.

*Figure 5: WRF PPI_TDH vs. Flow Rate chart*




Multiple sets of data from different time periods or from different pumps can be shown together on one Pump Efficiency chart by adding a Reference Chart. For example the WRF PPI_TDH vs. Flow Rate chart with two pumps shown in Figure 6.

*Figure 6:      WRF PPI_TDH vs. Flow Rate Chart with Two Pumps*




Outliers in the data shown on the charts above were succesfully removed by 'cleaning' the data using a BizBlock calculation with an 'if statement', by removing the data which was outside a defined data range and/or one standard deviation from the mean of the data.

A water network balance BizBlock calculation and chart was made as shown in Figures 7 and 8.

*Figure 7:      Water Network Balance BizBlock*

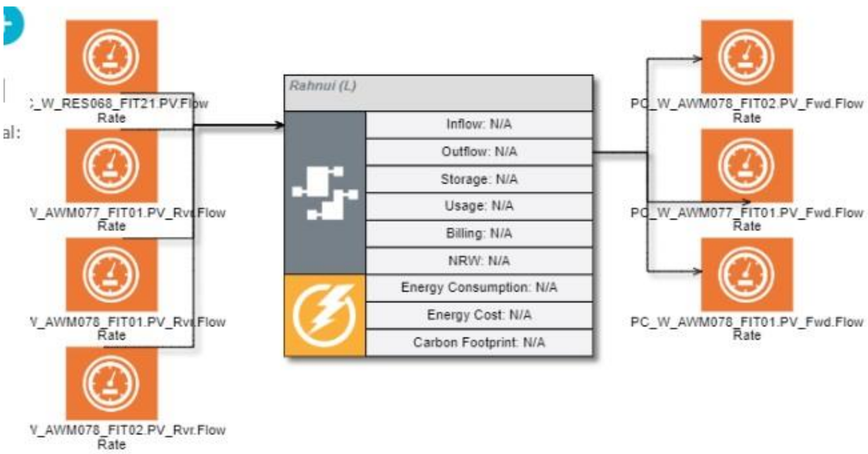
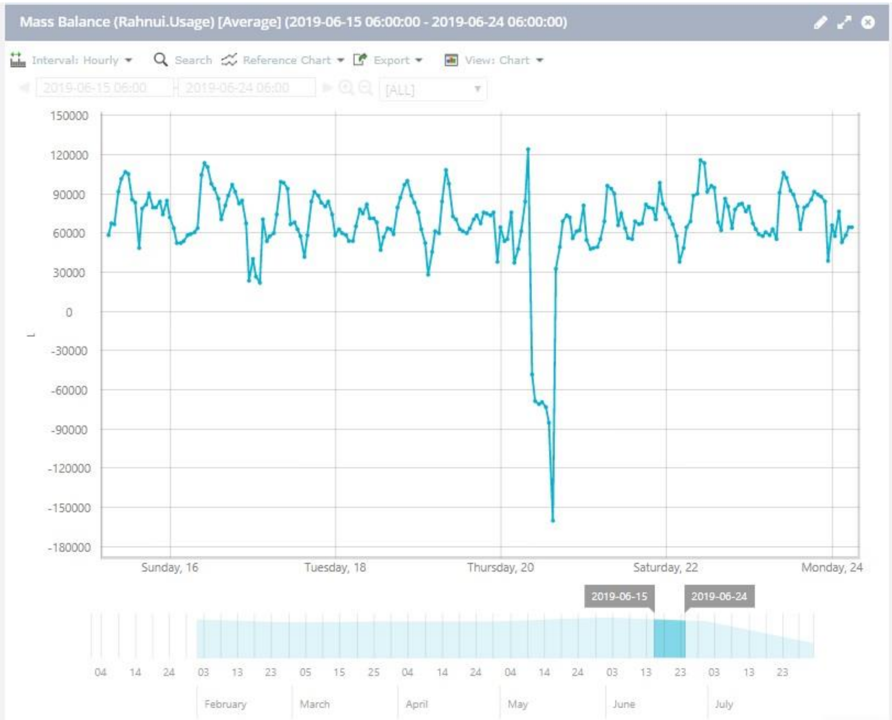



*Figure 8:      Water Network Balance Chart*




A water infrastructure leakage index BizBlock calculation and chart was made as shown in Figures 9 and 10.

*Figure 9: Water Infrastructure Leakage Index BizBlock*

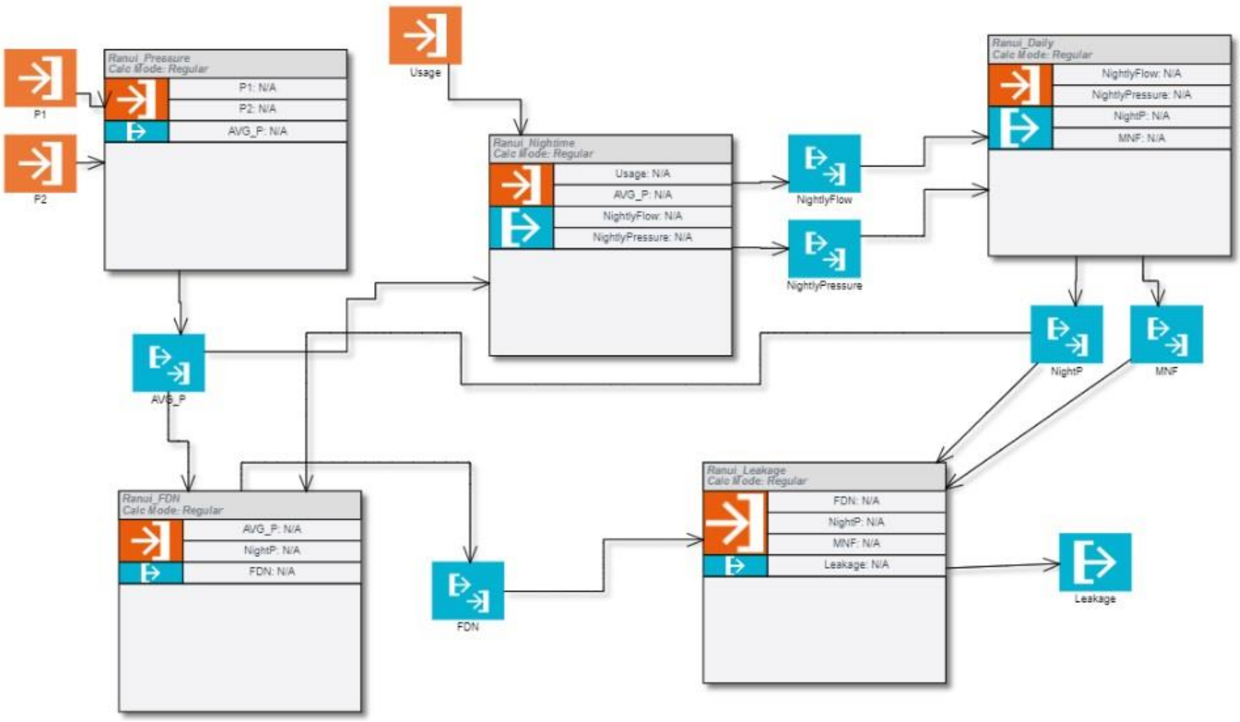
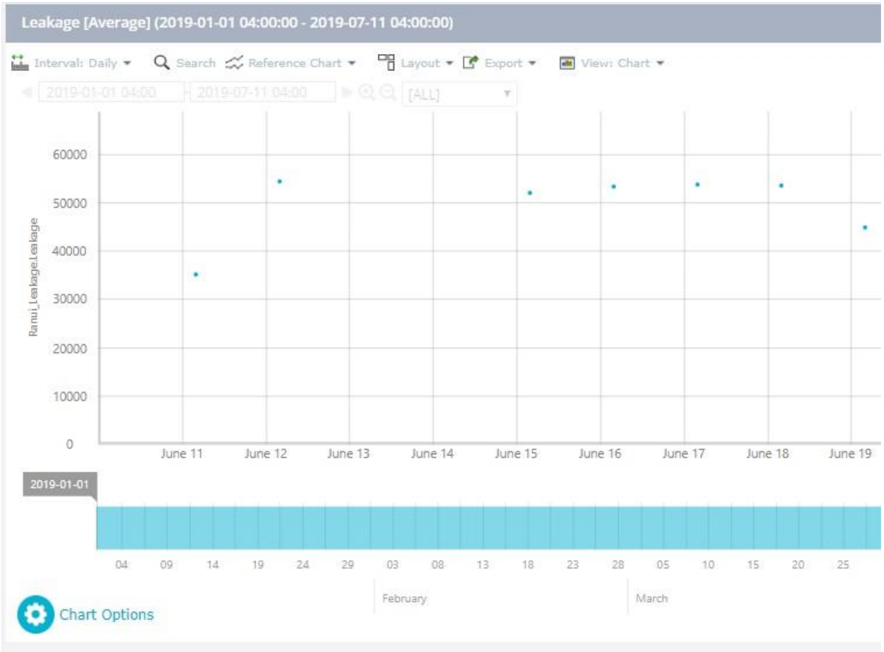



*Figure 10: Water Infrastructure Leakage Index Chart*




As shown in the figures above pump performance, water network balance and water infrastructure leakage index calculations were completed using SCADA data in Info360 software. Continuous monitoring of pump performance is expected to be achievable when live SCADA data is used. Theoretically, following further analysis of the Pump Efficiency charts on Info360 actions could be taken based on whether a pump is operating at its baseline manufacturer's efficiency, such as pump refurbishment or choosing to run the most efficient combination of pumps at the appropriate speeds. By running their pumps more efficiently, Wellington Water could save significant amounts of energy consumption, money and greenhouse gas emissions.

Info360 helped streamline and standardise the calculations by using the SCADA data directly within the software. BizBlock calculations and charts were shared with and repeated easily by other users. BizBlocks provided a template which could be extended and scaled with more scope and longer data timeframes automatically.

Info360 required that the pump stations had flow rate, suction pressure, discharge pressure, motor speed (Hz) and motor power SCADA sensors in order to complete the Pump Efficiency calculations.

Pressure sensors are typically located further away from the pump so that the individual pump fitting and static pipework losses (including any throttled valves) between the pump and the pressure sensor were counted as an artificial decrease in the head difference across the pump. It is believed this problem could be addressed by including these losses, based on site measurements and/or correction factors, in the Pump Efficiency BizBlock calculations.

Many magnetic flow meters are installed on the pump station's common rising main which means the SCADA data needs to be filtered for when the individual pumps are operating alone to be able to complete the Pump Efficiency BizBlock calculations.

Various sensors at the pump stations are understood to have errors due to a number of factors including age, incorrect installation and sensor drift over time. These errors may be able to be corrected by onsite instrument calibration or by applying a correction factor to the Pump Efficiency BizBlock calculations e.g. correcting against snapshot pump performance test data.

It is recommended that snapshot pump performance testing should continue to be performed regularly on pumps larger than 30 kW using the thermodynamic method where possible and with the full range of typical operating conditions where possible, to provide an accurate baseline and to confirm the validity of the SCADA data. It is expected that continuous monitoring of pump performance using SCADA data will provide enough information to plan pump refurbishment and pump station upgrades for pumps smaller than 30 kW.

An alternative to using SCADA data for continuous monitoring of pump performance is using thermodynamic data from a permanently installed thermodynamic continuous monitoring system, such as the MicroPM by Robertson Technology. The thermodynamic data could be uploaded like SCADA data into Info360 or other software. This could eliminate the limitations and barriers found with using SCADA data and provide more accurate data.

The unique benefit of using the thermodynamic technique of pump performance testing (snapshot or continuous) is that it provides flow rate, head difference and motor power readings which are independent from pump station SCADA sensor readings and has calibrated accuracy and repeatability. The thermodynamic technique measures the pump efficiency directly via differential temperature measurements across the pump. The flowrate is then calculated from the pump efficiency, pressure difference and power measurements, which means existing magnetic flow meters are not required. In that sense the thermodynamic method provides independent flow measurement for individual pumps.

Magnetic flow meter accuracy is effected by air entrainment, cavitation, operating point, build-up on pipes and sensors, and pipe work configuration (often requiring long lengths of straight pipe before and after the flow meter).

The thermodynamic technique’s flow rate measurement uncertainty is less than 2.0% with water (Robertson, 2015). The suppliers of magnetic flow meters suggest that their meters are at most 1.0% accurate, but because their meters aren’t necessarily installed in the best places and can be out of calibration their accuracy may generally be around 5 to 10%. Flow measurement with wastewater is expected to have a greater uncertainty with the thermodynamic technique as for magnetic flow meters. Typical thermodynamic technique probe installation on pump pipework is shown in Figure 11.

*Figure 11: Typical Thermodynamic Probe Installation*

Further investigation is recommended into how Info360 can be used to automatically 'redflag' which pumps are operating significantly below their manufacturer's pump data.

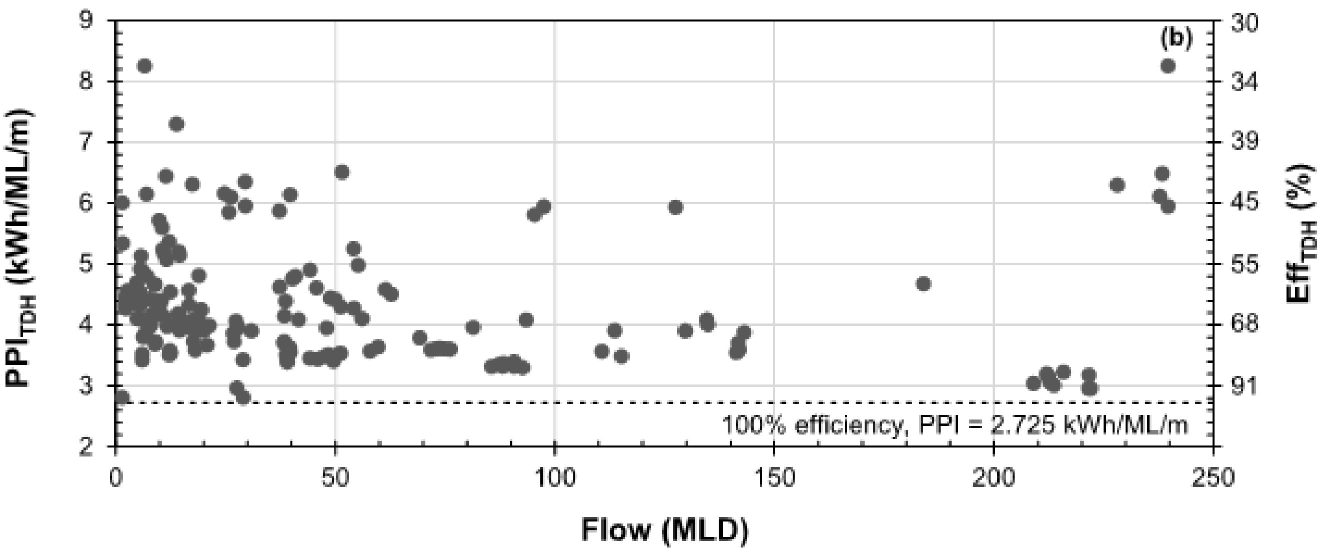
## 2.2 PUMP PERFORMANCE BENCHMARKING DATABASE

The WRF used the pump performance indicators PPI_TDH and PPI_STATIC for benchmarking individual pumps against the pump performance benchmarking database developed in their study. PPI_TDH was deemed best suited for when the pump's pipeline system was static-dominated (vs. friction dominated) and the more comprehensive metric to characterise pump energy performance. PPI_STATIC was deemed a better indicator of pump performance for throttled pumping systems.

PPI_TDH is calculated by dividing the motor power consumption (in kilowatt-hours) by the volume pumped (in millions of liters) and the head difference across the pump (or total dynamic head (TDH)) (in meters). The units of PPI_TDH are kWh/ML/m. The WRF's PPI_TDH indicator normalises the specific energy against the head produced by the pump, thus providing a more consistent comparison across pumps of different pressure ranges and independently from pump type or speed.

The WRF PPI_TDH pump performance database is shown in Figure 12.

*Figure 12: WRF PPI_TDH Pump Performance Benchmarking Database*




The WRF PPI_TDH values varied from 2.8 to 8.2 and a value of 4.0 was defined for when pumps are operating efficiently, based on the 50th percentile of the database. The lower the PPI_TDH value the more efficiently the pump is operating. The WRF determined that if the PPI_TDH exceeded the 75th percentile, an energy performance improvement opportunity might exist for the particular pump and further analysis should be conducted. Energy performance improvement opportunities recommended by the WRF included pump refurbishment, operating pumps nearer to their best efficiency points, selecting individual or combination of pumps that provide the best efficiencies and using variable speed drives to eliminate pressure reducing valves (which waste energy).

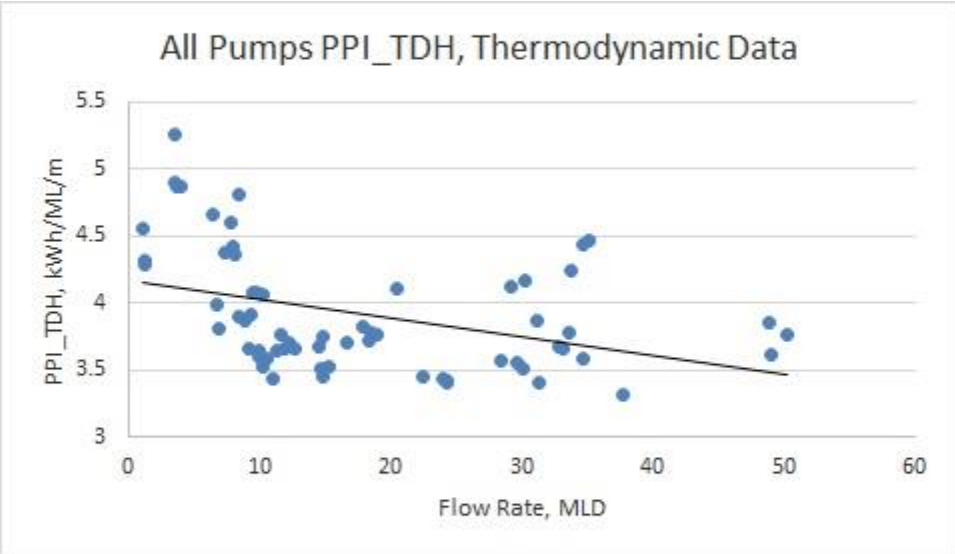
The WRF's study's major challenge was the accessibility and accuracy of the SCADA data and instrumentation. For example, at least 50% of the pump stations included in the study did not have either suction or discharge pressure data (a work around was used where the pressures were estimated using the flow rate data and manufacturer's pump data). Many pump stations had common magnetic flow meters which meant that the SCADA data needed to be sorted for when individual pumps were running. Instrumentation reading errors were found to cause accumulated errors in the PPI_TDH calculations. And the SCADA data had various data gaps and inconstancies which had to be to be 'cleaned' up before the data could be used.

Cardno have now developed a PPI_TDH pump performance benchmarking database using historical thermodynamic technique pump performance test data from 66 pumps from three New Zealand water utilities. Cardno believes that the thermodynamic pump testing data is of superior quality compared to SCADA data in terms of its accessibility and accuracy. The benefits of thermodynamic pump performance data over that from SCADA sensors was described in Section 2.1.

The thermodynamic test data, which was obtained using the Robertson Technology P22 system, corresponded to the pumps' duty flowrate based on operational information gained from the utilities at the time of testing. The instantaneous motor power reading in kilowatts was used along with the flow rate in million liters/hour and total dynamic head (TDH) in meters to calculate PPI_TDH.

The PPI_TDH pump performance benchmarking database from thermodynamic test data is shown in Figure 13.

*Figure 13: PPI_TDH Pump Performance Benchmarking Database from Thermodynamic Test Data*



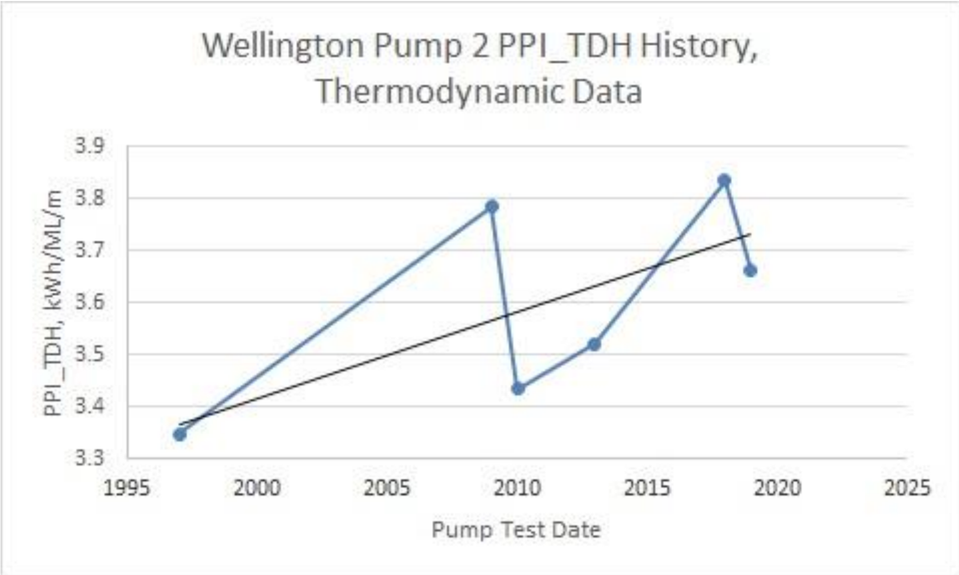

Note the flow rate has been converted to million liters/day.

The PPI_TDH values vary from 3.3 to 5.3 and a value of 3.8 is defined for when pumps are operating efficiently, based on the 50th percentile of the database. As for the WRF database, if the PPI_TDH exceeds the 75th percentile, in this case a value of 4.2, an energy performance improvement opportunity might exist for the particular pump and further analysis should be conducted.

For pumps with flow rates under 10 MLD and over 10 MLD PPI_TDH values of 4.3 and 3.7 are defined for when pumps are operating efficiently respectively. The 75th percentile values were 4.7 and 3.8 for flow rates under 10 MLD and over 10 MLD respectively.

Figure 14 shows the PPI_TDH history for one pump. The first PPI_TDH value of 3.3 comes from the manufacturer's pump data and is based on the pump's operational duty point. The subsequent values come from thermodynamic test data. The PPI_TDH deteriorates until the pump is refurbished, indicated by an improvement in the PPI_TDH.

*Figure 14: PPI_TDH History for One Pump from Thermodynamic Data*




It is recommended that the PPI_TDH pump performance benchmarking database using thermodynamic test data is considered by councils as a tool to help them get the most out of their pumps through preventative maintenance and achieve their sustainability targets. The database should be developed further and continuously updated within New Zealand and worldwide. Thermodynamic data from either snapshot testing or from permanently installed continuous monitoring systems, such as the MicroPM system by Robertson Technology, could be used.

# 3 CONCLUSIONS

## 3.1 CONTINUOUS MONITORING OF PUMP PERFORMANCE

Pump performance, water network balance and water infrastructure leakage index calculations were completed using SCADA data in Info360 software. Continuous monitoring of pump performance is expected to be achievable when live SCADA data is used. Theoretically, following further analysis of the Pump Efficiency charts on Info360 actions could be taken based on whether a pump is operating at its baseline manufacturer’s efficiency, such as pump refurbishment or choosing to run the most efficient combination of pumps at the appropriate speeds. By running their pumps more efficiently, Wellington Water could save significant amounts of energy consumption, money and greenhouse gas emissions.

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Info360 required that the pump stations had flow rate, suction pressure, discharge pressure, motor speed (Hz) and motor power SCADA sensors in order to complete the Pump Efficiency calculations. It is important the onsite instrumentation is installed correctly and is calibrated.

Pressure sensors are typically located further away from the pump so that the individual pump fitting and static pipework losses (including any throttled valves) between the pump and the pressure sensor were counted as an artificial decrease in the head difference across the pump. It is believed this problem could be addressed by including these losses, based on site measurements and/or correction factors, in the Pump Efficiency BizBlock calculations.

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It is recommended that snapshot pump performance testing should continue to be performed regularly on pumps larger than 30 kW using the thermodynamic method where possible and with the full range of typical operating conditions where possible, to provide an accurate baseline and to confirm the validity of the SCADA data. It is expected that continuous monitoring of pump performance using SCADA data will provide enough information to plan pump refurbishment and pump station upgrades for pumps smaller than 30 kW.

An alternative to using SCADA data for continuous monitoring of pump performance is using thermodynamic data from a permanently installed thermodynamic continuous monitoring system, such as the MicroPM by Robertson Technology. The thermodynamic data could be uploaded like SCADA data into Info360 or other software. This could eliminate the limitations and barriers found with using SCADA data and provide more accurate data.

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The PPI_TDH values vary from 3.3 to 5.3 and a value of 3.8 is defined for when pumps are operating efficiently, based on the 50th percentile of the database. As for the WRF database, if the PPI_TDH exceeds the 75th percentile, in this case a value of 4.2, an energy performance improvement opportunity might exist for the particular pump and further analysis should be conducted.

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Malcolm Robertson, Robertson Technology Australia

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