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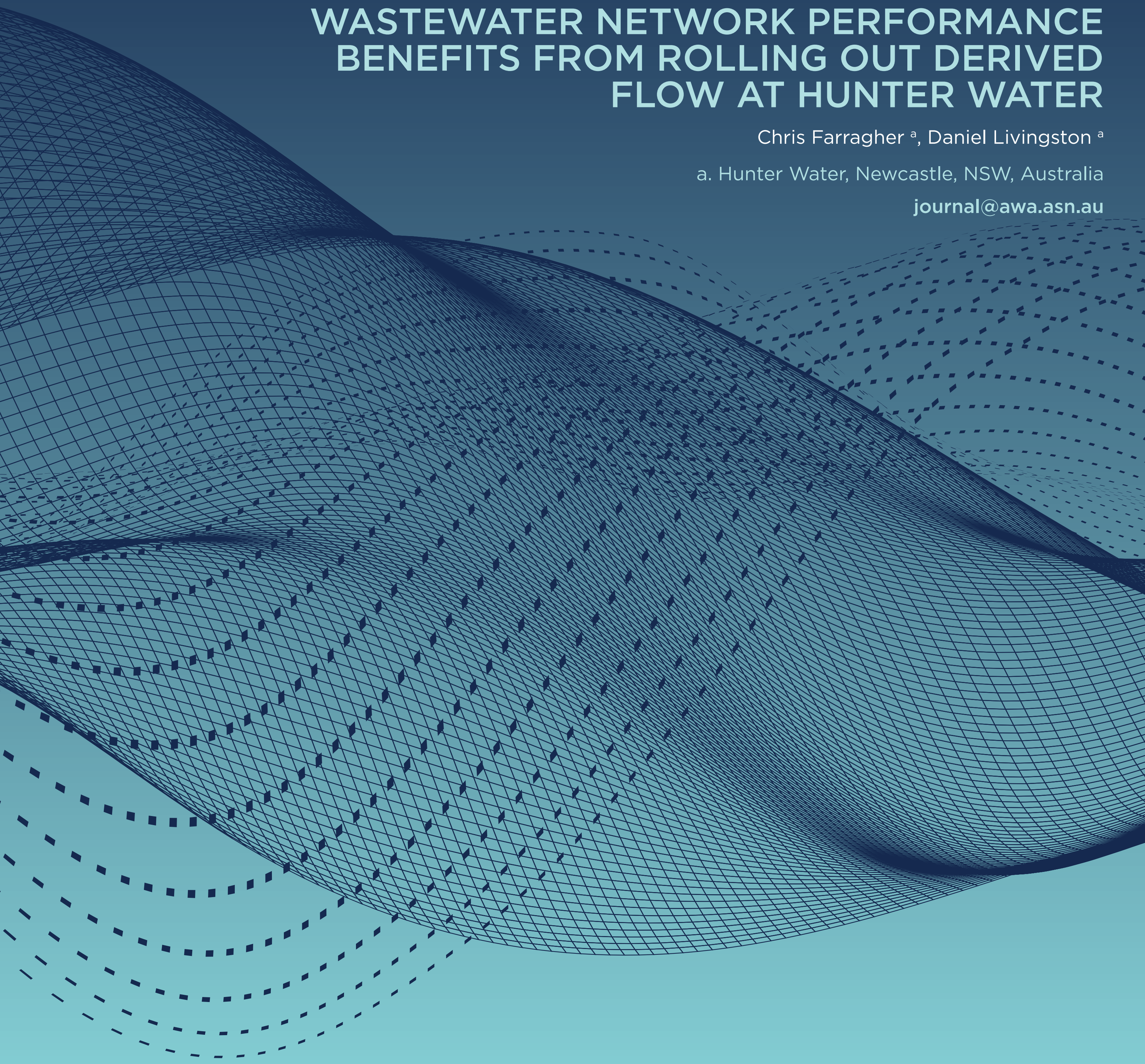

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ABSTRACT

Measurement of flow in wastewater networks provides multiple benefits including significantly improved maintenance outcomes for reduced cost and earlier detection of overflows. However, measuring wastewater flow is a challenge to achieve cost-effectively due to the larger number of wastewater pumping stations compared to a typical water network, as well as the frequency of fouling of flow meters. Hunter Water has rolled out a flow measurement methodology for all its wastewater pump stations that derives the flow from existing instrumentation, giving a measure of pump flow performance. All that was required was software changes. The resulting benefits dwarf the small cost.

INTRODUCTION

Hunter Water is the water and wastewater services provider for over 600,000 people in the Lower Hunter region of New South Wales, based in Newcastle. Hunter Water owns and operates over 500 wastewater pump stations. Due to the relatively small size but high number of stations, as well as the frequency of fouling of equipment, wastewater pump stations are not typically fitted with flow meters. However, knowledge of flow volumes through each wastewater pump station presents desirable benefits and opportunities. So, Hunter Water has used existing monitoring and control equipment to calculate each pump's flow performance, and in turn calculate a flow measurement through each wastewater pump station simply through modification of the control logic code installed at each site, all at minimal cost. This paper outlines how that was done and the resulting benefits.

"Derived Flow" is the term Hunter Water uses for an onsite calculation of pump flow performance derived from monitoring data available at the station from the Programmable Logic Controller (PLC) and Supervisory Control and Data Acquisition (SCADA). The existing monitoring data comes from level sensors that are used to control the operation of the pump station (Burgess, 2008). Pump flow performance is used to measure hourly station inflow, by multiplying a pump's assessed flow rate by that pump's run time in that hour to derive a mass flow through that pump. The mass flow through each pump is totalled to obtain a station outflow volume. A comparison of well level at the beginning of the hour to at the end of the hour is used to convert that outflow volume into an inflow volume for the hour. This secondary measurement is the basis of a Hunter Water system that systematically monitors pump station mass inflow, allowing the calculation of a 24-hour moving total of inflow from a station's own gravity catchment. Flows from upstream catchments are netted off the measured flow through the station

– a process Hunter Water refers to as “Mass Balance”. That moving 24-hour total allows for an early warning of sewage building up in the network, or of sewage leaving the network.

In the past, when there were pump station performance issues, it was often not clear whether they were driven by high inflows or poor pump performance. This lack of clarity would at times delay and even stall intervention, which meant that pump condition and performance issues that should have been addressed were not always identified in a timely manner. Delayed action comes at a cost, including increased maintenance costs as performance issues would be identified after significant asset condition deterioration.

The lack of clarity also led to increased capital expenditure on pump station capacity upgrades due to assumed higher inflows when the issue may have been pump performance. Pumps operating inefficiently also led to increased energy costs.

Another cost impact was the increased maintenance cost of poorly targeted maintenance scheduling that did not correspond to asset condition. Pump condition is predicted much more reliably on the basis of variable service conditions than on the basis of time (Ahmad & Kamaruddin, 2012). However, the lack of performance monitoring data meant that maintenance could only be scheduled based on time elapsed since last service, even though that is a relatively poor predictor of condition. In Hunter Water’s experience, pumps with good service conditions can have a pump life an order of magnitude higher than pumps with poor service conditions (e.g., a poor duty point, frequent chokes, presence of abrasives in the sewage, poor station pipework design, etc).

Not only does detection of chokes limit damage to impellers, bearings and motors, but the excess vibration at a choked pump can weaken and damage the pedestal, fittings, pipework and even footings of the pump mount. Damage increases with length of time that a choke is undetected.

This mechanism for pump station condition deterioration can also be caused by cavitation of a pump over time. Cavitation can lead to uneven wear of the impeller with similar flow-on effects to a choke. Measurement of flow performance helps to identify cavitation via performance deterioration.

Flow measurement can also give warning of air accumulation in the rising main, as the presence of air pockets typically reduces a station’s pump flow performance. Air in the main can also result in surging flow rates when the pump starts, which becomes visible in the pump flow measurement. When there is air routinely in part of a ferrous rising main, it can cause premature failure of the main through corrosion.

Long term data analysis of station flow measurement also enables better upgrade investment planning and more targeted intervention to reduce inflow and infiltration – thus better utilisation of capex.

A better managed and controlled wastewater network uses less energy (and associated greenhouse gas emissions) due to pumps operating more efficiently and also via improved reduction of unwanted inflow and infiltration of stormwater and groundwater. Energy is also saved by identifying and correcting worn non-return valves, that cause flow recycling and can result in almost a tripling of pumping at a station. The non-return valves at Bolwarra 1a station were replaced after Derived Flow identified substantial leakage. The subsequent reduction in pumping was quantified, and the resulting electricity cost savings alone are expected to be $9,400 per year.

Furthermore, there is an overall benefit for operation and management of the wastewater network performance through the application of the principle often known as “what gets measured gets managed” (Klaus, 2015). Capital investment to improve the network - such as initiatives to reduce inflow and infiltration - can be more effectively targeted and, once implemented, measured for effectiveness.

From 2011 to now, Hunter Water has taken a journey toward more strategic and cost-effective maintenance of wastewater pump stations, through derived measurement of flow at pump stations.

METHOD

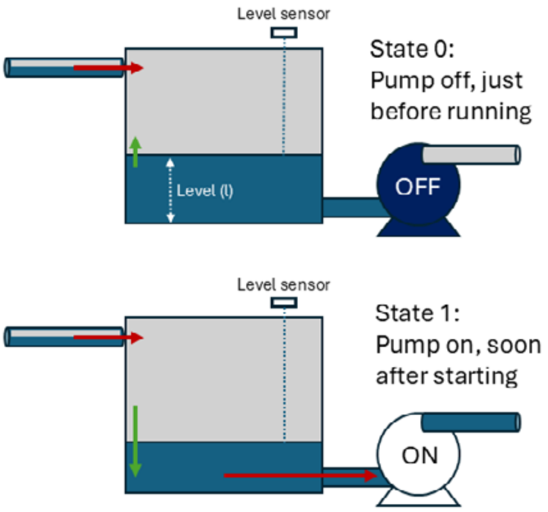
Flow meters are the natural go-to for measuring flow; but they are costly (Salguero, Deatrick, & Johnson, 2015). Flow meters have been installed on the discharge pipework of some wastewater pumping stations throughout Hunter Water's area of operations, but they tend to be damaged due to corrosive sewage. Accuracy is also less reliable due to the possibility of a partially full pipe.

There are a range of physical devices used to measure wastewater flow (Salguero, Deatrick, & Johnson, 2015; Kulin, 1984). In addition to physical devices, some utilities are using machine learning (artificial intelligence) to model estimates using a variety of other known data (Zhou, Li, Snowling, & Barclay, 2023). An approach that bears some resemblance to the method used by Hunter Water is the use of depth measurement along a main to estimate its flow rate (Tomperi, Rossi, & Ruusunen, 2023).

Hunter Water had previously successfully measured what it terms depletion flows, the flow rate in and out of a water reservoir. The method involves using high resolution storage level measurement data combined with the known cross-sectional area of the reservoir tank to calculate a depletion flow. Hunter Water identified a similar opportunity at wastewater pump stations. Existing level sensors determine pump cut-in and cut-out levels. Combining this existing data (i.e., the change in level against time) with known cross-sectional area of the pump well makes deriving a pump's flow rate performance possible through calculation.

There are a number of possible approaches to calculating a Derived Flow. The one used by Hunter Water could be described as an automatic drop test. Given that there is always some amount of inflow, the change in level due to the operation of the pump can best be estimated by calculating the difference in the rate of change of the well level before and after a pump state transition from off to on, and likewise, before and after a pump state transition from on to off.

The calculation is the difference between dl/dt (where l = level of water in well in mm, t = time in minutes) multiplied by the cross-sectional area (in m^2), divided by 60 to get the flow (in Litres/second). See Figure 1 below for a description of the calculation of the pump flow rate as derived via the transition of the pump state from off to on. A corresponding derivation of the pump flow rate can be made associated with the transition of the pump state from on to off.



Level sensor measures well level. Flow calculation is derived from that measurement as follows:

l = level in mm, t = time in min

dl/dt_0 = rate at which well is filling with pump off*

dl/dt_1 = rate at which well is filling with pump on*

A = known cross sectional area of well in m^2

Derived pump flow = $(dl/dt_0 - dl/dt_1) \times A / 60$

Units: $mm/min \times m^2 / (s/min) = L/s$

* Note that dl/dt is negative when the well level is falling. Hence, in most cases, the derived pump flow rate is based on the rate of rise of the well level prior to the pump starting being added to the rate of fall of the well level, measured soon after the pump starts.

Figure 1: How pumped flow calculation is derived (for initial pump flow performance) from existing level sensor equipment

This calculation is performed at both the cut-in and cut-out of the pump, with the calculation being based on snapshots of the well level rate of change taken 0 seconds before cut-in or cut-out, and generally 30 seconds after cut-in or cut-out. The time after cut-in or cut-out can be adjusted based on the operating conditions of that particular station. Shorter times minimise the risk of inflow variability influencing the measurement, but also come with increased likelihood that pumped flow rate has not yet reached a steady state.

The calculation of Derived Flow occurs at each change of pump state – i.e. twice for every time the pump runs. A decision is made for each station whether the calculation is likely to be more accurate at pump cut-in or pump cut-out, or the average of the two. Then the PLC filters the data by taking the median of the last 11 results, to remove outliers. For example, if once in a while the pumped flow from an upstream station distorts a measurement taken at the start of pumping, then that result will be an outlier, and successfully discarded by the method described above.

The calculations are all done by the programmable logic controller (PLC) at the pump station, and are displayed on the SCADA page for that station. It is important that the calculation be done at the PLC rather than by the SCADA, taking advantage of the high resolution level data available on site, without burdening telemetry and centralised data storage.

Derived Flow is accurate as it embraces the methodology used by water authorities to verify the flow performance of pumps, which is the drop test. Importantly, Derived Flow at Hunter Water has been designed to be auditable, making it possible to verify through a desktop audit whether the resulting measurements are a true quantitative measure of the pump's performance. That process is utilised whenever Derived Flow is being used for quantitative purposes such as determining if a pump's performance meets a design specification.

Another method of deriving a calculated flow is to use the rate of the well filling to calculate a live measure of inflow, and assume a constant inflow rate whenever the station is pumping. This assumption allows a calculation of the pump flow rate based on the volume change in the well as a result of the pump down, and the time taken to pump the well down.

For some stations the Derived Flow method may not be the best measure of station mass inflow due to irregularities in the way the pump is called to start or soft starters taking time to reach a steady state, as calculation of volumetric flow through the station assumes that pumps start and stop at full flow. For such cases, where the introduced error is unacceptable, it may be better to use a mass flow calculation based on the rate of well level rising when pumps aren't running, rather than combining pump flow performance with pump run times to determine a mass flow volume. The rising well method would also be superior for some stations on common rising mains, since the flow performance of the pump cannot be counted on to always be the same. Importantly, the rising well method is automatically inferior to using pump performance (as determined using Derived Flow) for mass flow measurement for any station that receives pumped flows from upstream stations, as in those cases the assumption that inflow remains static when a pump is running breaks down dramatically. Ideally each pump station in a network could choose between these two methods depending on these characteristics (i.e., whether there is a soft starter, whether there is a common rising main and whether or not inflow is dominated by upstream pumped flows). Hunter Water has only implemented Derived Flow for measuring flow performance, as described in Figure 1, because the number of stations where the alternative method would be better is very small. Likewise, the Mass Balance calculations are based solely on the inflow measurement that is based on Derived Flow.

RESULTS

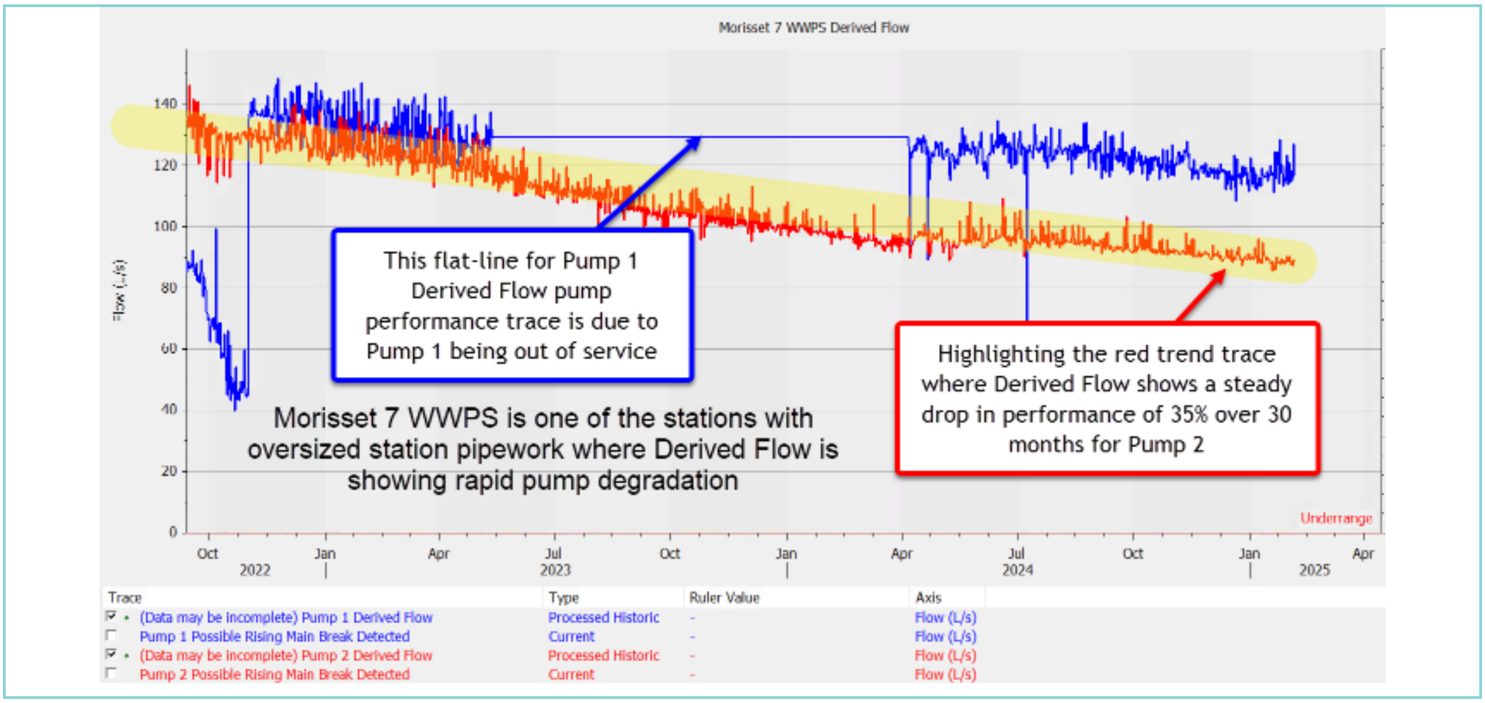
The implementation of Derived Flow calculations has enabled Hunter Water to begin to transition from time-based pump maintenance to condition based pump maintenance. This has resulted in a shift to more proactive maintenance that is better targeted to the pumps that need maintenance based on their condition. The current strategy is to use Derived Flow to improve the in-service performance of the pump fleet, without increasing costs, by progressively shifting from time-based maintenance schedules. Ultimately, it is hoped that Derived Flow will allow both better performance of the pump fleet, and a reduction in maintenance costs. In addition to the cost savings associated with more appropriately targeted pump maintenance scheduling, several secondary ("bonus" or unexpected) benefits have also been observed. Derived Flow and Mass Balance also provide additional clues regarding the condition of non-return valves. The shape of the rate of change signal reveals when a rising main is draining in between pump runs and the relative overnight flow rate can also be used as supportive evidence as backflow from the rising main appears as inflow in the station inflow measurement.

Mass Balance has provided earlier detection of blockages, and Mass Balance as well as Derived Flow has given notification of rising main breaks, leading to less environmental pollution from wastewater overflows. Note that Derived Flow can detect rising main breaks via the subsequent jump in pump flow performance. At times, the scheme has allowed Hunter Water to intervene before an environmental release occurs. This is when a network blockage results in a sufficient drop in inflow at a station to be detected, before the blockage results in flow to the environment. Other times, an overflow still happens, but the volume of release is much less, due to SCADA alarms bringing attention to abnormal pump flowrates or flow Mass Balance anomalies.

Capital upgrades have been deferred in some cases through realisation that capacity issues were the result of pump condition-based performance issues rather than inherent design limitations. Planning decisions are generally improved because base assumptions can be cross checked with measured pump flow rates and network flow volumes reported by the system.

Operating costs for electricity have also been reduced by more prompt maintenance when pumps have been poorly performing.

Flow measurement also provides insights into design principles for wastewater pump stations and rising mains to ensure sufficient minimum flow velocity for clearance of rocks. There is a design principle that says that the flow velocity in a station's pipework is a critical element in pump service life and maintaining good performance. If flow velocity in the rising main is insufficient (e.g., less than 2 metres per second), heavy debris can fail to clear the station, and accumulate at the pump, increasing pump wear rates. Derived Flow has shown a loose correlation between stations with low pipework velocities and stations with rapid pump performance loss. Figure 2 is a screen capture from SCADA which shows the rapid drop in flow performance at a station with low sewage velocity in its station pipework (from oversized pipes).



This flat-line for Pump 1 Derived Flow pump performance trace is due to Pump 1 being out of service

Morisset 7 WWPS is one of the stations with oversized station pipework where Derived Flow is showing rapid pump degradation

Highlighting the red trend trace where Derived Flow shows a steady drop in performance of 35% over 30 months for Pump 2

Trace	Type	Ruler Value	Axis
☑ • (Data may be incomplete) Pump 1 Derived Flow	Processed Historic	-	Flow (L/s)
☐ Pump 1 Possible Rising Main Break Detected	Current	-	Flow (L/s)
☑ • (Data may be incomplete) Pump 2 Derived Flow	Processed Historic	-	Flow (L/s)
☐ Pump 2 Possible Rising Main Break Detected	Current	-	Flow (L/s)

Figure 2: Morisset 7 pump station is an example where Derived Flow has shown accelerated rates of pump wear, evidenced by the drop in flow performance

Measurement of Derived Flow has also highlighted incorrect asset data. For an upgrade plan for the Morpeth catchment, about 20% of stations across that entire wastewater network had data issues that were picked up via reference to flow performance data provided by Derived Flow. This enabled the planning team to perform analysis and plan upgrades based on more accurate information.

The highlighting and removal of accumulated or embedded errors in asset information also helps resolve operational incidents. One example experienced by Hunter Water was when pump flow was throttled to fix a temporary operational incident, but this was forgotten and left. In another incident, a temporary pump had been placed in service as a stop gap, but as the change was not documented, this was forgotten and left in place more permanently. Derived Flow measurement highlighted these anomalies.

We now also regularly verify pump station performance at commissioning. Drop tests had not been typically performed and flow measurment devices are rarely installed. At new assets, Derived Flow facilitates early confirmation of the pump performance as a simple by-product of commissioning.

At Belmont 1 Waste Water Pump Station (WWPS), Derived Flow identified that the impeller of a pump had been trimmed without any formal record. So the assumed flow did not match reality. The Derived Flow calculation highlighted the issue. In absence of flow measurement, Hunter Water's planning team would have assumed the station was producing the documented design flow and made incorrect conclusions about the volumes of sewage passing through the station.

Another benefit is the streamlining of upgrade investment planning decision-making. An example where Derived Flow helped, but could have helped more if used earlier, was the case of a proposed upgrade for Buttaba 2 WWPS. A capacity upgrade was in early stages of upgrade planning, including having a capital budget provision in the portfolio. Designers had assumed incorrect station duty flow because of incorrect or misinterpreted data. The pump documented flow rate was much less than the actual performance measured by Derived Flow. Upgrade planning assumed the documented flow performance was accurate, which assumed single pump duty, whereas in reality, the flow value was for a single pump's flow with two pumps running. This was a triplex station. Reference to Derived Flow avoided unnecessary work, but also illustrated that checking Derived Flow even earlier would have avoided mistaken assumptions on station performance. Learnings such as this have changed Hunter Water's practice to ensure early checking of Derived Flow in planning work.

All these examples of additional benefits of Derived Flow measurement, and many more not recorded in this paper, highlight the value of long term pump performance data providing multiple insights for operations and upgrade planning.

DISCUSSION

Standardising code at WWPSs has enabled the success of implementing this. However, the roll-out has not been without human error. A coding error resulted in a calculation error whereby all flow calculations were out by around 12.5%. This is in the process of being corrected, but requires the PLC code at each station to be updated – requiring a field visit by a technician.

Ensuring realisation of benefits of Derived Flow measurements also requires the modification of workflows. For example, in the early days of its roll-out, a rising main break was missed because a SCADA alarm was missed that could have resulted in earlier detection of the break. In that case, a community member reported the overflow triggering remedial action where the alarm from Derived Flow should ideally have led to remedial action prior to noticeable adverse impacts on the public or environment.

These examples highlight the importance of paying close attention to the role of humans in interacting with improvements to performance data – both in ensuring data accuracy as well as ensuring that data insights are noticed and acted on.

CONCLUSION

The roll-out of PLC/SCADA changes to enable measurement of wastewater pump station flows has been a cost-effective initiative for Hunter Water. The Derived Flow method described can achieve high levels of accuracy with careful implementation. All that is required is software changes. There are multiple significant benefits for a relatively low-cost initiative that can be replicated in any water or wastewater storage application that has level sensors and PLCs. The benefits described will help managers and operators to make more informed decisions regarding pump asset management.

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Many Hunter Water staff and contractors have worked together to enable and continuously improve the implementation of Derived Flow measurement across Hunter Water's wastewater network. The tireless and high-quality work of many is acknowledged and appreciated.

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