WATER AND WASTEWATER SYSTEMS IMPROVEMENTS THROUGH DIGITAL OPERATIONS ANALYSIS

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ABSTRACT

An ever-growing wealth of data is recorded and stored for water and wastewater systems driven by exponential growth in the availability of sensors and digital networks. Unfortunately, there is still a significant gap between the vast quantity of captured process data and the ability to analyse it effectively to inform decision making. A large proportion of operating data remains trapped and unutilised in storage, providing no value.

This paper describes the application of data analysis techniques on historical operating data to optimise pumping and treatment system operations. We present several project examples where digital operations analysis was applied to discover energy savings and maximise system performance through automation improvements.

Our approach combines water and wastewater engineering expertise with advanced data analysis techniques. We begin by applying system and equipment specific algorithms to process years of operating data and evaluate performance, identifying where improvements could be made. For some systems, current performance may be close to optimal, but for many others significant savings can be achieved through automation improvements including optimised setpoint management, equipment transition control, and control algorithm tuning. If the potential savings offer a compelling return on investment, proposed changes are implemented and verified.

Our application of digital operations analysis has resulted in energy savings of up to 15% and associated carbon emission reductions, increased operating time at steady state and under control, and prolonged equipment life. While many optimisation studies focus on potential capital improvements, automation improvements are relatively low cost, can be implemented immediately, and offer a significant return on investment with payback times often within a few years followed by ongoing annual savings.

With digital operations analysis we can make use of our operating data resources to identify and implement improvements that optimise the performance of our water and wastewater systems.

KEYWORDS

Digital technologies, data analysis, automation improvements, energy savings, low carbon

PRESENTER PROFILE

Jared Thorpe is a chemical engineer with over 25 years of experience in applying advanced analysis techniques to improve the performance of engineered systems. He is an innovator and developer of unique software applications that enhance decision making from planning through design, construction, start-up, and operations for water and wastewater facilities.

1. INTRODUCTION

1.1. DATA RICH, ANALYSIS POOR

With the emergence and rapid growth of the Internet of Things (IOT), the world has become increasingly rich with data. In the water industry, sensors have become less expensive, more accurate, and increasingly ubiquitous, along with the network systems and automation platforms that receive and store operating data.

This gathering of data is a key component to unlocking systems optimisation through digital technologies, but there is a significant lag in the application of analysis techniques on the vast stores of available operating data to discover and implement performance improvements.

Figure 1 below presents a digital analysis process to achieve systems optimisation.

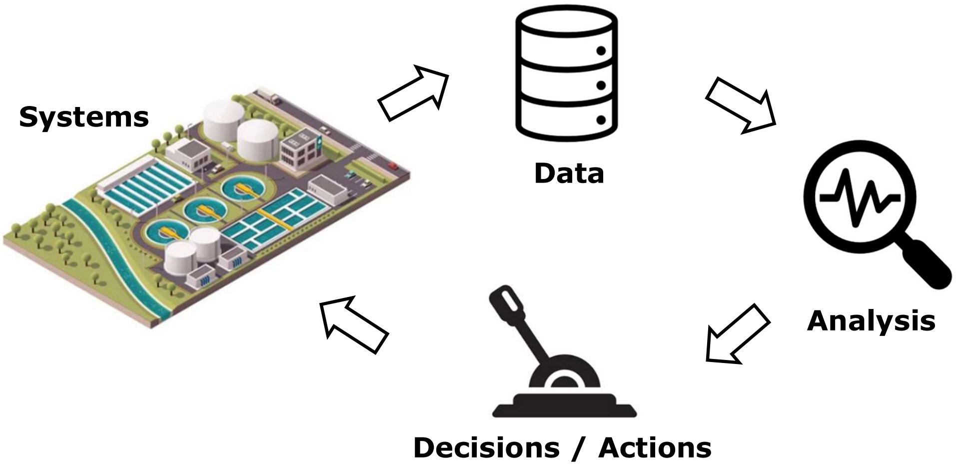


Figure 1: Systems Optimisation through Digital Technologies

This paper presents examples of analysis techniques applied to historical operating data for water and wastewater facilities with a focus on systems that present improvement opportunities with significant potential benefit (“digital low hanging fruit”). These opportunities can provide a great first step down the path of a digital transformation.

1.2. DIGITAL LOW HANGING FRUIT

The challenges to reach the aspirational goals of a digital transformation can be overwhelming, making it difficult to take the first step down the path of investment and implementation.

A great way to start this journey is to identify potential systems within water and wastewater facilities that present as strong cases for data analysis and potential improvement. Characteristics of such systems are:

- Significant impact on overall system performance
- Adjustable operation

Examples of systems that match these criteria are:

- Medium to large pump stations
    - Wastewater lift stations
    - Raw water conveyance
    - Treated water supply to distribution
- Aeration blowers
- UV reactors

By some estimates, pumps account for over 10% of world energy consumption, and are a significant contributor to energy use and associated carbon footprint for water and wastewater systems.

Aeration blowers are the largest consumer of energy for many wastewater facilities, and UV reactors are often the second largest energy consumer for facilities where they are part of a tertiary treatment process.

These systems typically have multiple equipment units that can be turned on and off, and adjustable settings for speed or power output, and operating decisions are driven by facility operators and automation programming with potential for improvement.

A lot of the systems optimisation work for water and wastewater has been focussed on capital improvements, typically replacing equipment with new and better performing units. This paper presents a case for a greater focus on automation improvements, where significant return on investment can be achieved by getting the best out of existing systems and equipment.

Application of smart analytics on operating data for these systems can provide insight into current operation, and the potential for viable improvements.

2. SMART ANALYTICS

2.1 METHODOLOGY

A data analysis approach that applies system specific algorithms can extract information from historical operating data that characterises behaviour and measures performance. These algorithms combine engineering and process knowledge with data analytic techniques.

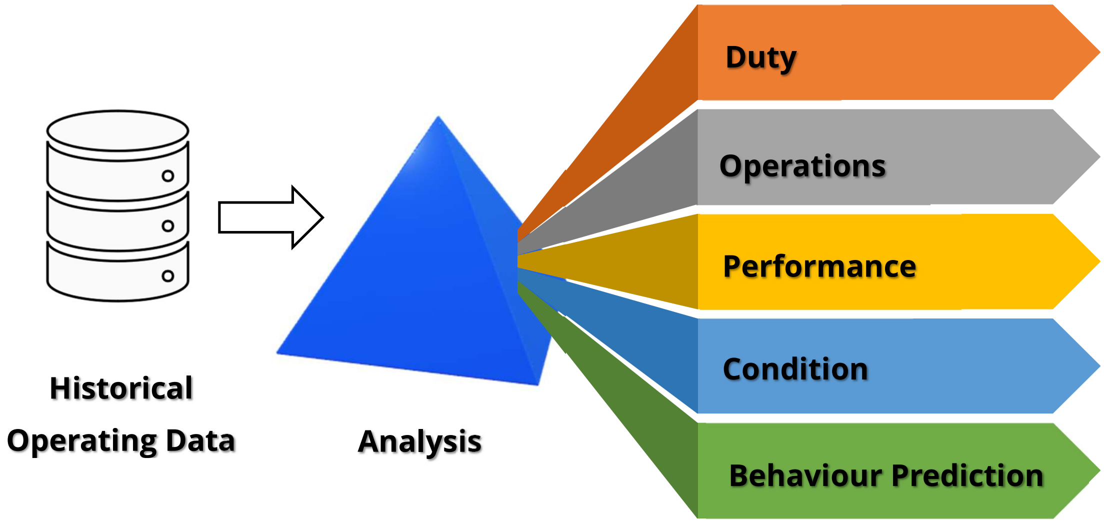


Figure 2: Operating Data Analysis Approach

The historical operating data to be used for analysis is defined by:

- Relevant system tags
  - Flows
  - Pressures
  - Levels
  - Speeds
  - Equipment statuses
  - Positions
  - Current draws
  - Power consumption
  - Set points
- Timestep or frequency of data
  - Typically, 15 – 60 seconds
- Operating period
  - Often 1 or more years of operation

Each set of historical operating data to be used for analysis should be defined based on an understanding of the system of interest.

Raw operating data often requires filtering to remove anomalies and erroneous values and to smooth out some parameters with inherent measurement noise prior to application of analysis techniques.

2.2 DUTY

System duty can be presented as the duration of operation at specific operating conditions. Figure 3 below presents a duty surface for a finished water pumping station at a water treatment facility. The altitude of the presented surface (z axis) represents time operating under conditions of flow and head (represented by the x and y axes).

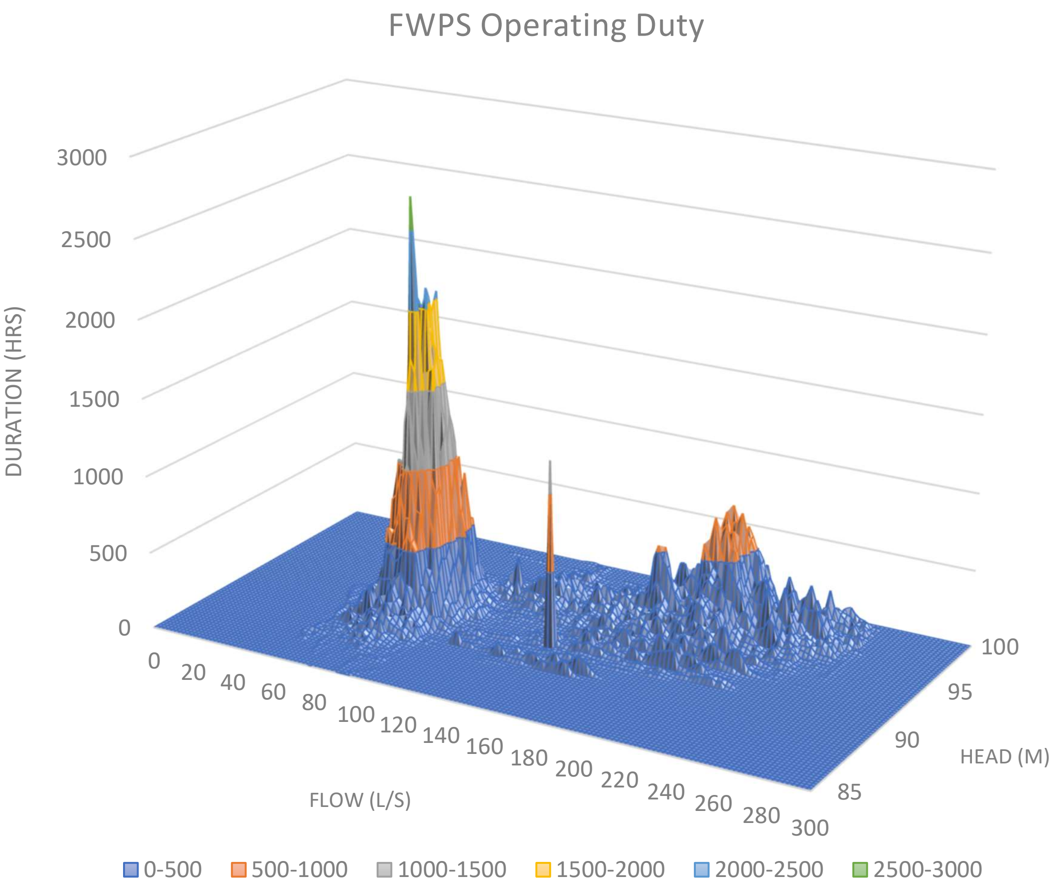


Figure 3: Operating Duty for a Finished Water Pump Station

It can be observed for this system and operating period that a significant duration of operation occurs around 2 regions of flow and corresponding system head. The greatest frequency of operation occurs at lower flows which may not be where this pump station is most efficient.

Figure 4 below presents a duty surface for an aeration blower system at a wastewater treatment facility. In this case the duration of operation is presented over the range of air flow and discharge pressure conditions.

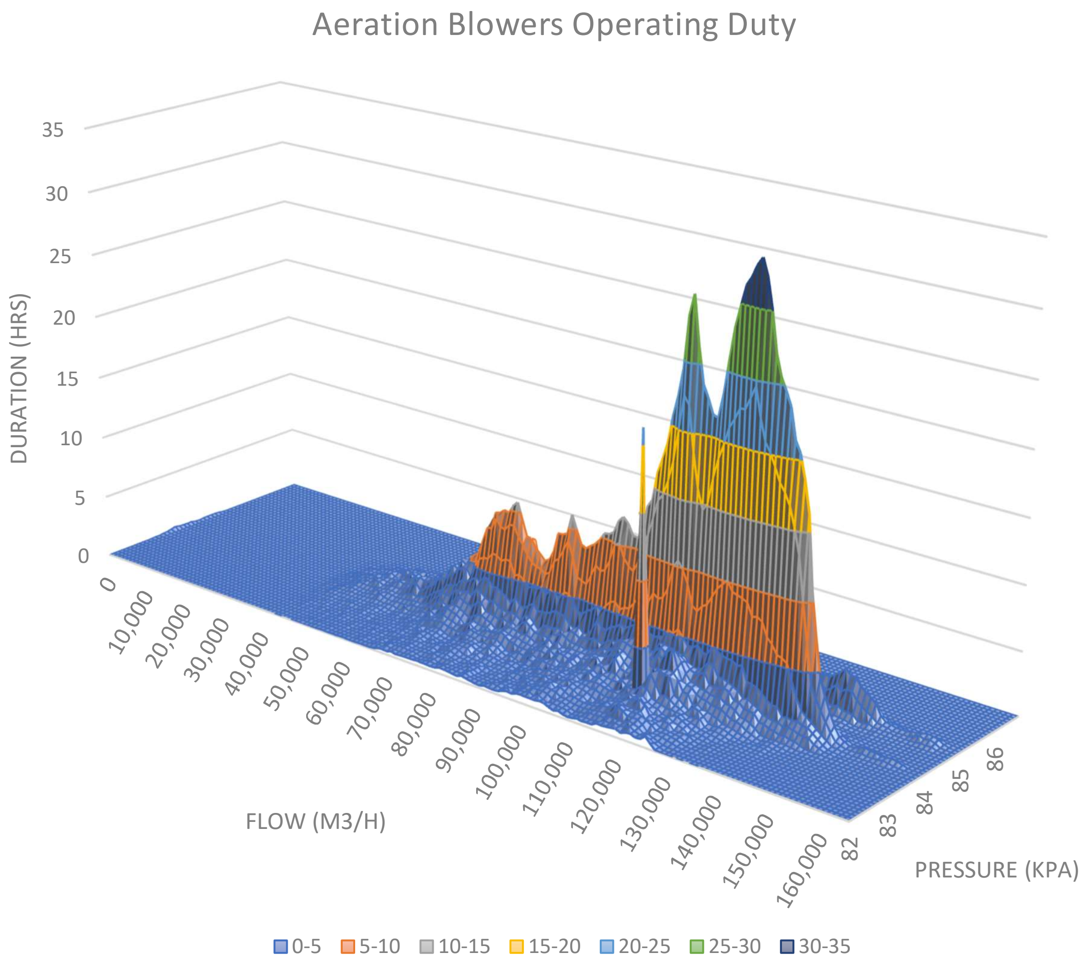
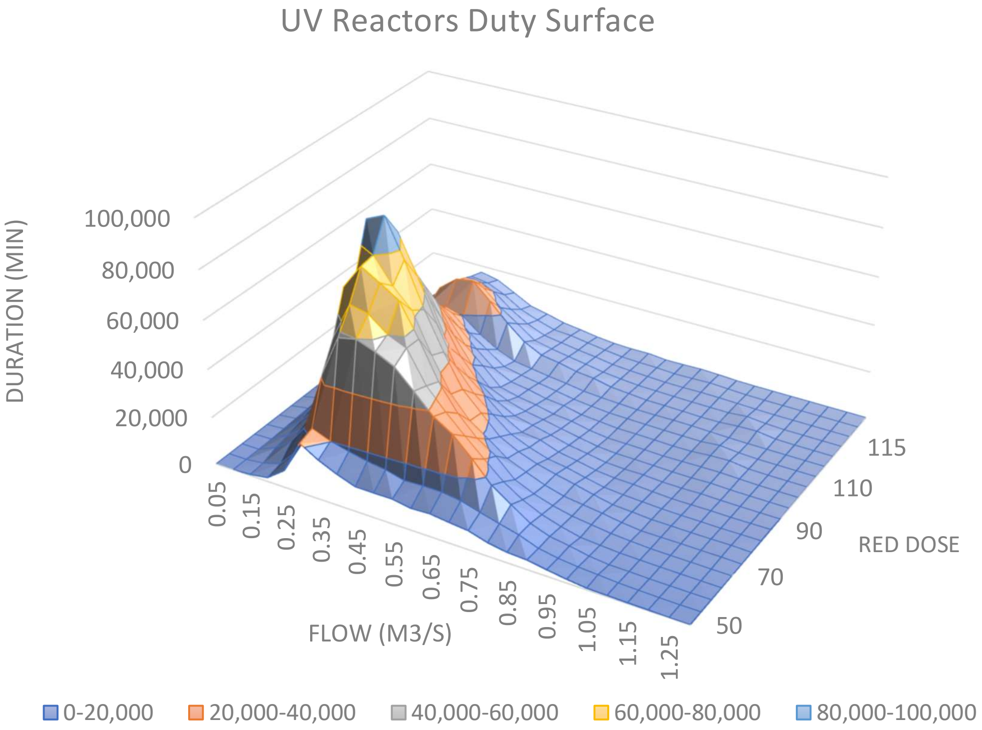


Figure 4: Operating Duty for an Aeration Blower System

It can be observed that a significant proportion of operation has occurred at a relatively constant pressure which reflects the nature of the control strategy for this system which is designed to maintain a constant discharge pressure.

Figure 5 below presents a duty surface for a set of UV reactors at a wastewater treatment facility. In this case the duration of operation is presented over the range of reactor flow and applied UV dose conditions, and duration is also presented over the range of combined UV channel flow and measured UV Transmittance (UVT).


UV Reactors Duty Surface

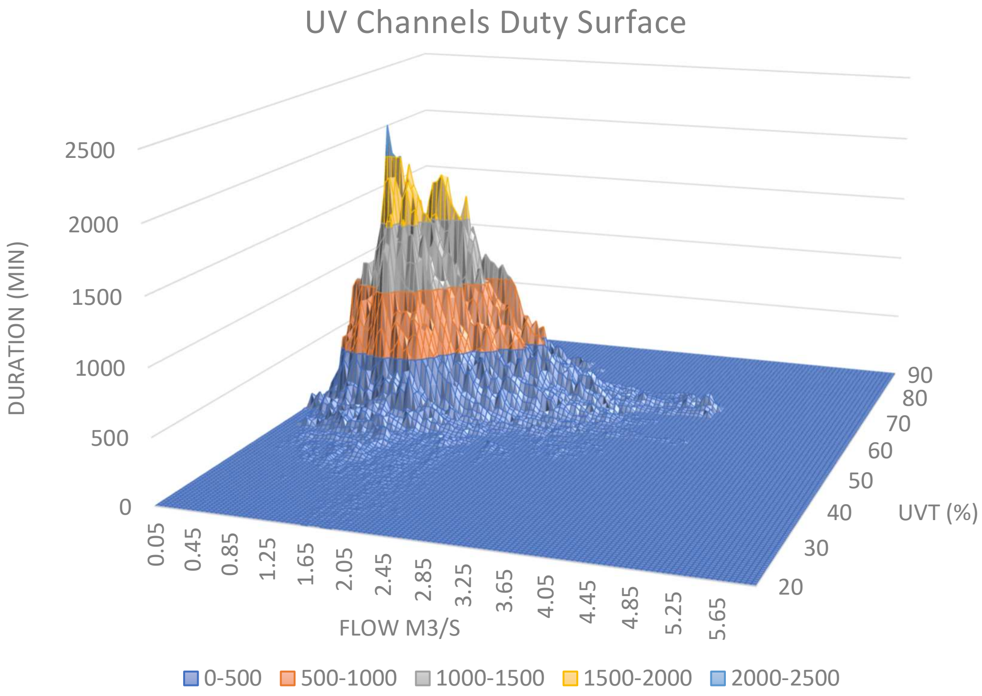

UV Channels Duty Surface

Figure 5: Operating Duty for an UV Reactor System

The duty surfaces presented above in figures 3, 4, and 5 provide insight to where these systems and associated equipment have operated and could lead to recommended set point and control tuning improvements to reduce variability and avoid operation under less desirable conditions with reduced performance.

2.3 OPERATIONS

System operations can be observed in terms of the duration for which combinations of units have operated under different conditions.

Figure 6 below presents the duration of different numbers of pumps in operation over the range of flow conditions for a treated water pump station. It can be observed that most operation occurred at higher flow conditions with 6 units running. It can also be observed that there are notable overlaps where different numbers of units have operated to achieve the same flows. This indicates potential for optimisation around the best number of units to operate at each flow condition if there is a relative difference in energy efficiency.

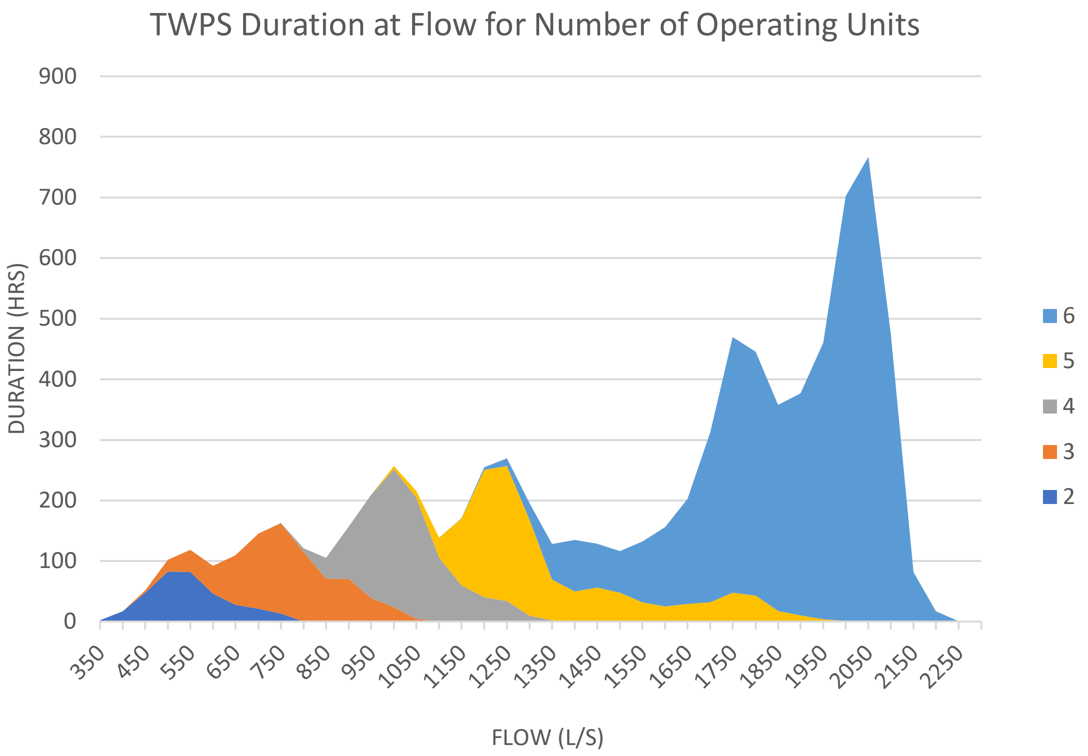


Figure 6: Units Operating at Flow for a Treated Water Pump Station

Start frequencies can be evaluated to ensure motors starts are kept within acceptable limits. An example of start frequencies analysis for a pump station can be observed in figure 7 below.

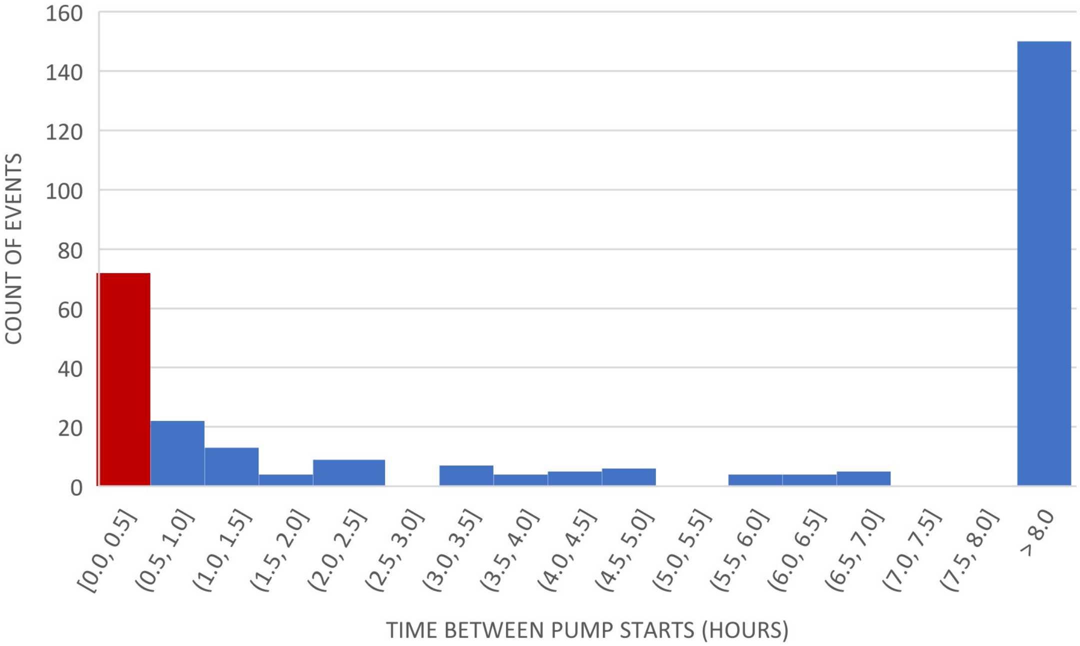


Figure 7: Start Frequencies for a Raw Water Pump Station

The sharing of operating duty for equipment groups can be reviewed to confirm that desired rotation strategies are being applied to manage unit run hours.

Figure 8 below presents the monthly run hours for each pump in a wastewater pump station.

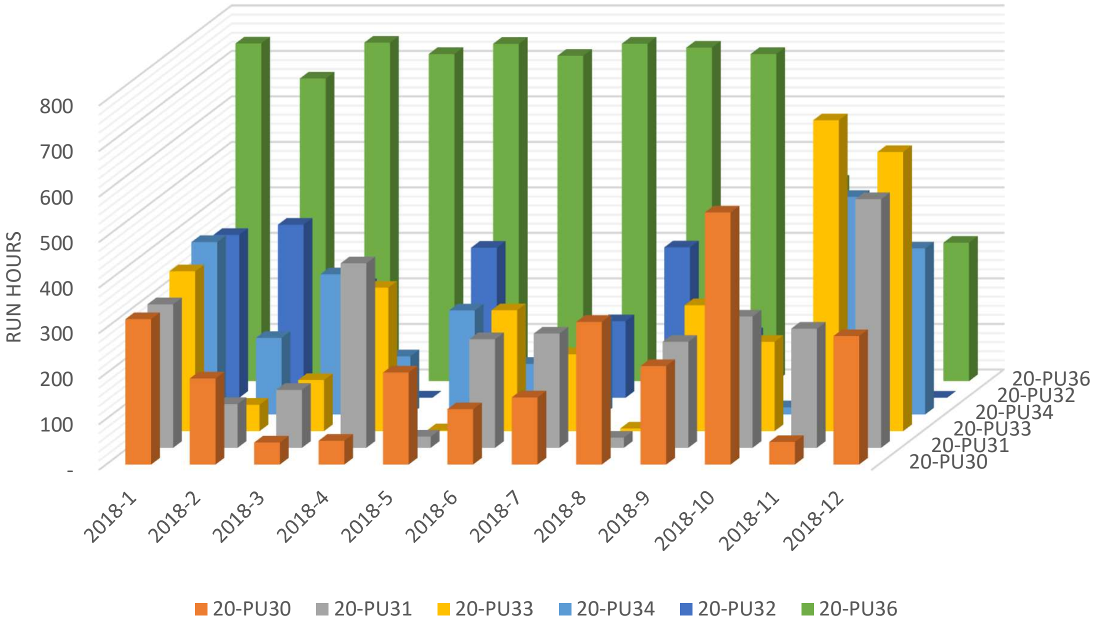


Figure 8: Monthly Run Hours for a Treated Water Pump Station Pump Station

2.4 PERFORMANCE

For many systems including pumps, blowers, and UV reactors, power consumption is a key performance measure with potential for improvement.

Figure 9 below presents power consumption and operating duration for different unit combinations at a specific flow for a pump station. It can be observed that operation at this flow condition occurs mostly with 4 or 5 pumps in operation, but the power consumption when 4 pumps are operating is less that with 5. This indicates that 5 pump operation under this flow condition should be reduced where possible to improve the energy efficiency of this pump station.

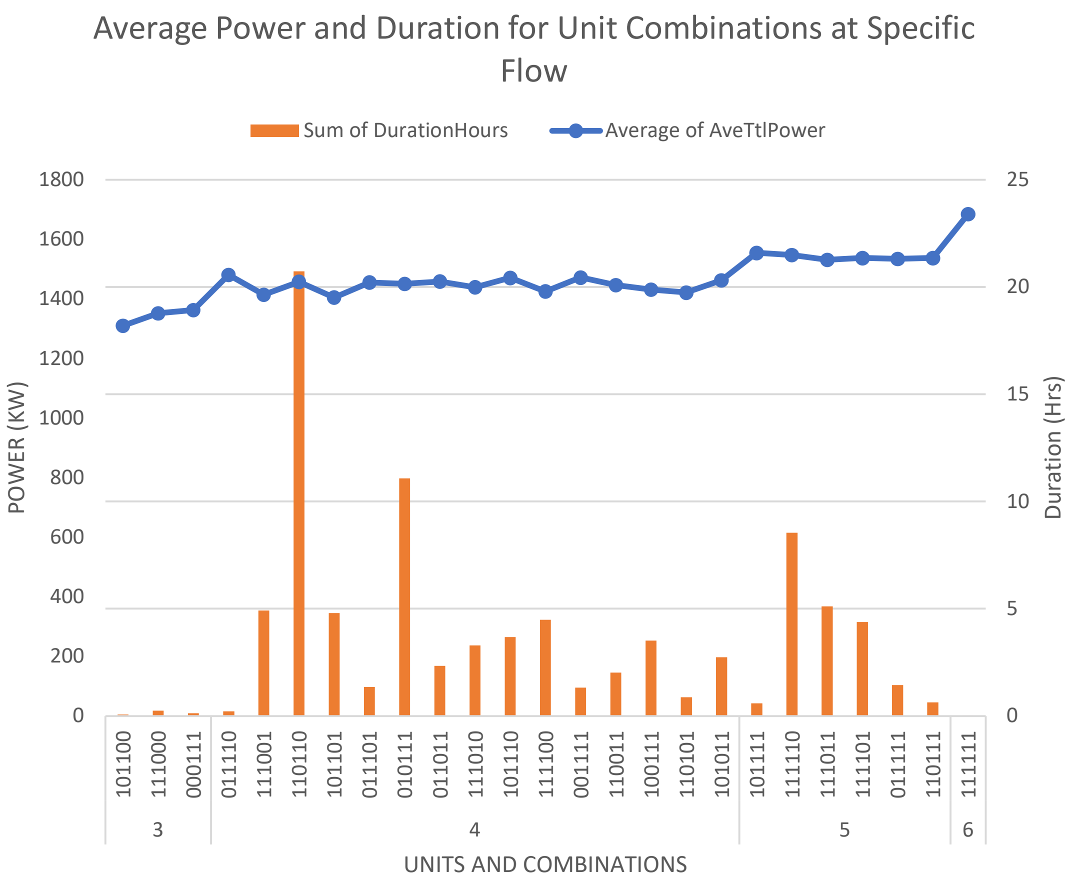


Figure 9: Power and Duration for Pump Unit Combinations at a Specific flow Condition

This performance analysis can be performed across the full range of operating conditions to establish the optimum combination of pumps for each.

Figure 10 below presents the power consumption for different numbers of pump units in operation over the range of flow conditions for a pump station. It can be observed that there are flow conditions where the number of units in operation are overlapped and there is a power consumption difference, typically favouring a lower number of units. In these comparative scenarios, a lesser number of pumps operating at the same flow condition will be running at higher speeds where they are likely to have been designed for best efficiency. For a greater number of pumps operating at the lower end of their flow range, the pumps are likely to be operating at lower speeds where they are also at a reduced efficiency.

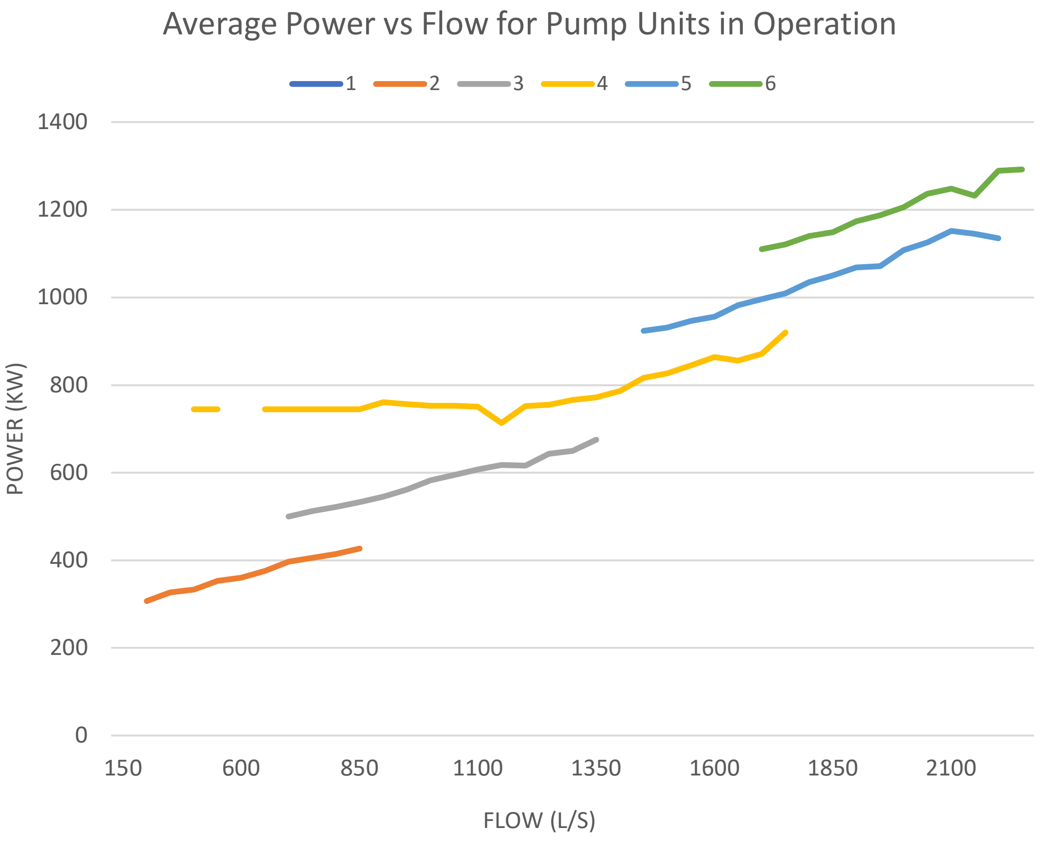


Figure 10: Power Consumption for Number of Units over Range of Pump Station Flow

Figure 11 below presents the average energy efficiency, optimum energy efficiency, and duration of operation for a raw water pump station over the range of flow conditions. A gap can be observed between the average and optimum energy efficiencies over most of the range of flow conditions, presenting an opportunity for optimisation of pump operations and corresponding energy savings.

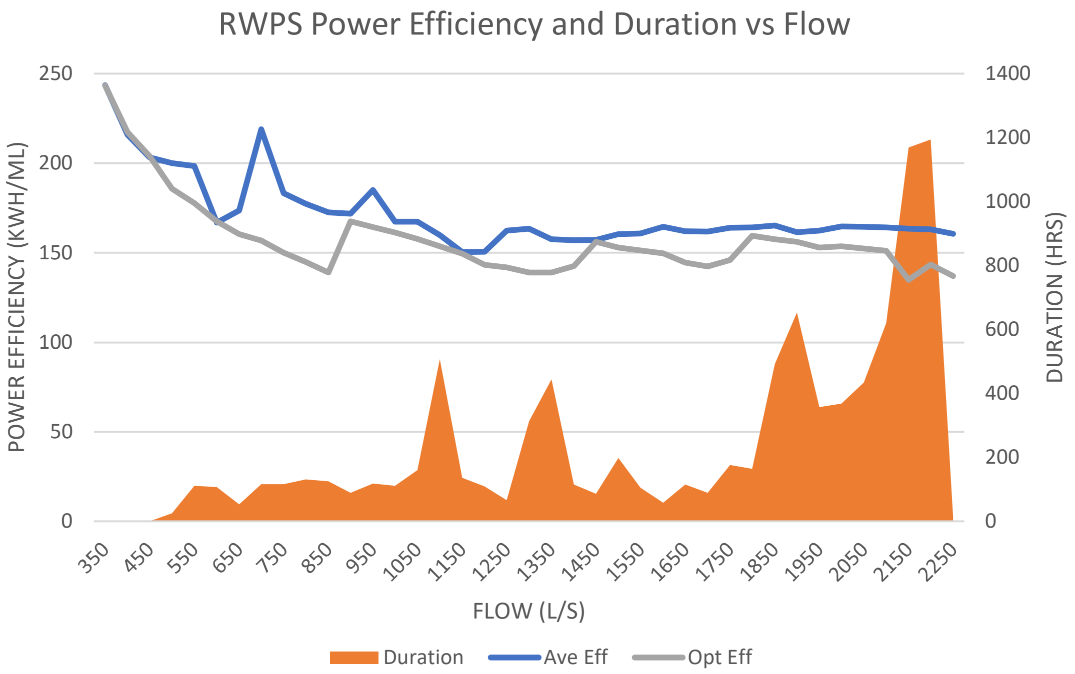


Figure 11: Energy Efficiency and Duration over Range of Raw Water Pump Station Flow

Figure 12 below presents an analysis of UV reactor performance in terms of power consumption and duration of operation over the range of operating flows at different UV dose set points. This information can be used to establish preferred flow and dosing set points for optimal performance.

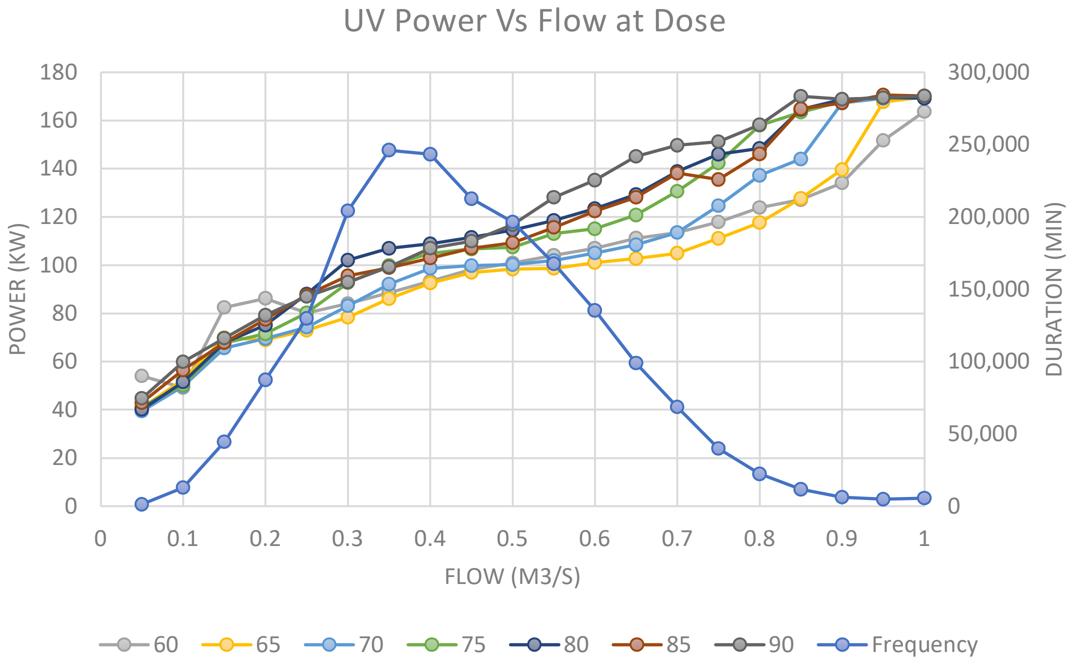


Figure 12: UV Reactor Performance

The performance of control loops can be evaluated based on the distribution of error (set point – measured variable). Figure 13 below presents the control performance of 2 aeration dissolved oxygen (DO) control loops that operate in parallel. A valve is controlled for each discharge location to attempt to maintain a desired DO set point. It can be observed that good control is achieved for the 104-system with most operation close to the DO set point. Conversely, for the 101-system control performance is poor with a wide range of measured DO and significant time spent under-aerating. This analysis points to a need to improve the tuning of the 101 system PID controller.

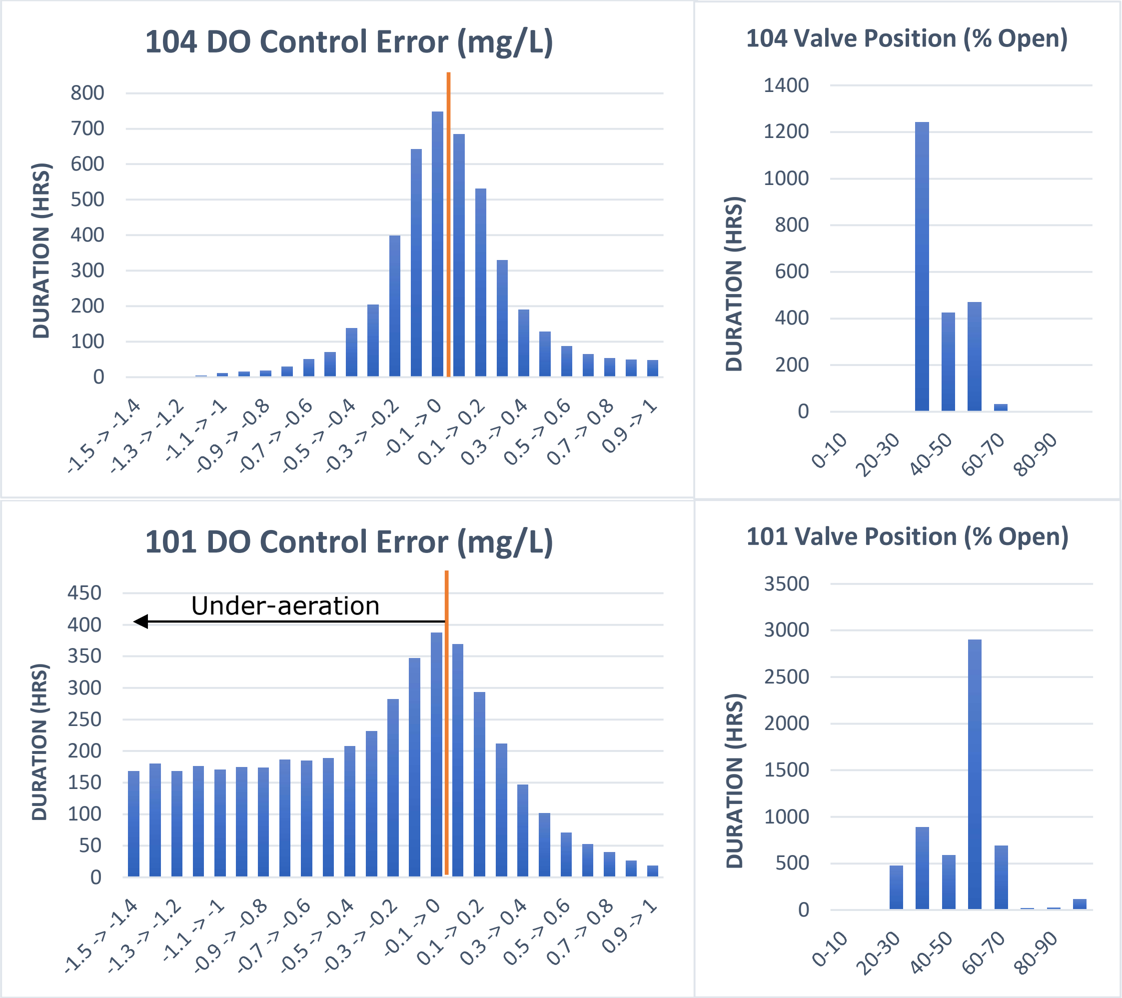


Figure 13: Aeration System DO Control Performance

2.5 CONDITION

Parameters that indicate equipment condition such as temperature and vibration for pump systems can be trended and evaluated for unexpected changes.

Long term pump performance can also be evaluated to establish rates of degradation from original pump performance. Reductions in both hydraulic capacity and energy efficiency can be observed for pump systems with different rates of decline expected for different pump types, fluid types, and duties. Sudden reductions in performance can indicate abnormal changes in pump condition that may require intervention.

Figure 14 below shows notable degradation in pump efficiency for pump 4 of a finished water pump station that eventually resulted in complete pump failure. This issue could have been addressed immediately upon performance change if ongoing performance monitoring was implemented, avoiding the resulting failure and a significant period of operation at reduced efficiency.

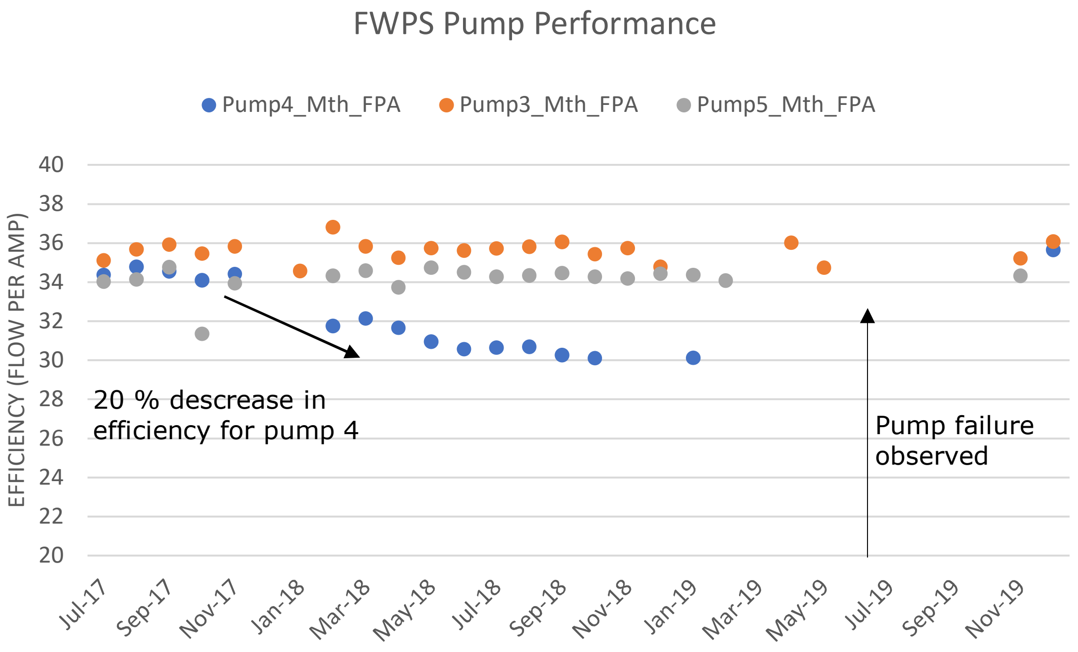


Figure 14: Finished Water Pump Performance Degradation

2.6 BEHAVIOUR PREDICTION

Data analysis can be used to establish models that predict system behaviour. A predictive model based on measured upstream variables can be used in a feed forward control strategy to significantly improve control performance for dynamic systems.

Figure 15 below presents the relationship between measured upstream wastewater flow and aeration system air flow for DO control. For this system it can be observed that flow changes correlate well for most operating conditions with a delay of 35-40 minutes between upstream wastewater flow and required aeration air flow. This presents a great opportunity to apply a model-based feedforward control strategy that uses the incoming flow to push the DO control strategy in the right direction while still utilising feedback control to dial in to require DO set points in each reactor zone.

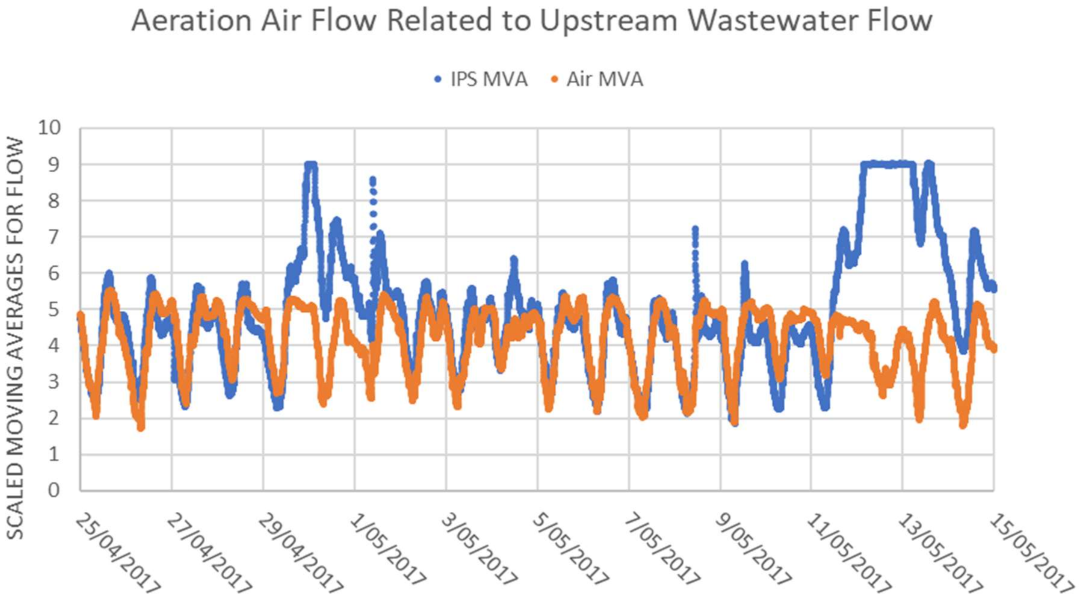


Figure 15: Wastewater Flow to Aeration Air Flow Relationship

3. AUTOMATION IMPROVEMENTS

3.1 STANDARD AUTOMATION

The current water and wastewater industry standard for automation is to achieve satisfactory and stable operation. Automation systems are designed with feedback control loops and equipment selection algorithms tuned to keep operation within acceptable process limits. A collection of alarms warn operators when operation occurs outside acceptable limits and may result in corrective actions.

The standard for many water and wastewater facility automation systems is failure avoidance and satisfactory operations. There is little evidence of automation design to drive optimised system performance. Several factors have led to sub-optimal automation systems:

- Technical expertise silos for process design and controls design
- A lack of performance measurement and associated objectives
- Risk aversion, based on an exaggerated perception of risk associated with automation changes
- Comprehensive data capture without subsequent analysis

This presents a golden opportunity to raise automation standards, supported by systems analysis to identify improvement opportunities, to extract best performance from water and wastewater systems.

3.2 ADVANCED AUTOMATION

There are many proven advanced automation techniques that are underutilised in our water and wastewater systems including:

- Advanced filtering
    - Classic moving average filters introduce data lag and are a blunt tool for handling anomalies
- Divergence warnings
    - Deviation of related process variables can provide early warnings for potential problems
- Optimised transitions
    - Selection of the optimal combination of units for best energy efficiency
- Set Point Management
    - Focussing operation on conditions where best performance is achieved
- Optimised loop tuning
    - PID control tuning can often be improved upon analysis
    - Adaptive tuning is underutilised
    - Cascade loops are often poorly tuned due to the complexity of interactions
- Model Assisted Control
    - Model-based feed forward control is potentially very powerful and vastly underutilised, particularly for wastewater treatment applications
    - Control strategies should take advantage of advanced information wherever possible
- Online performance analysis
    - Continuous system performance calculations built into automation can provide feedback and drive ongoing operations optimisation
    - Significant performance degradation can indicate requirement for maintenance interventions

Analysis of historical operating data can identify opportunities for these techniques to be applied to achieve system improvements. Examples of some of these techniques are presented below.

3.2.1 OPTIMISED TRANSITIONS

Transition strategies can be updated to ensure the optimal number of units are operating to achieve best energy efficiency. For the pump station performance presented in Figure 16 below, a new transition strategy achieves 6% energy savings by shifting operation from the previous blue performance trend to the new grey performance trend.

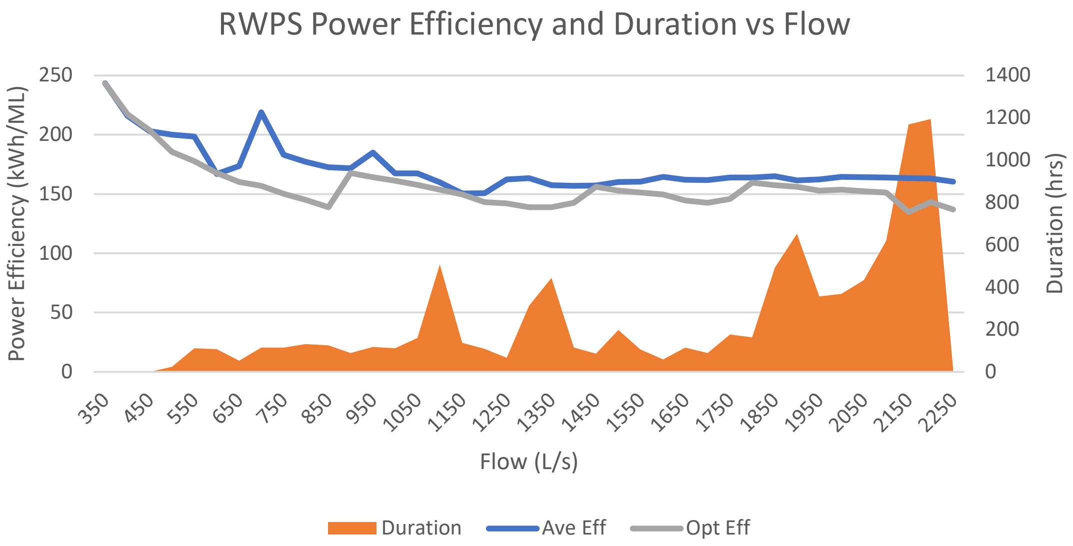


Figure 16: Energy Efficiency and Duration over Range of Raw Water PS Flow

3.2.2 SET POINT MANAGEMENT

For some systems, there is sufficient flexibility in the selection of operating set points to optimize around more efficient operating conditions. Figure 17 below presents a flow setpoint management strategy that prioritizes operation in the bands indicated by the black lines overlaying the efficiency and duration trends. For this water treatment facility, a combination of system storage and other facilities contributing to the downstream supply system allow for flexibility in setting flow set points for period of operation. Energy savings of up to 15% can be achieved for this system by operating most frequently within the recommended ranges.

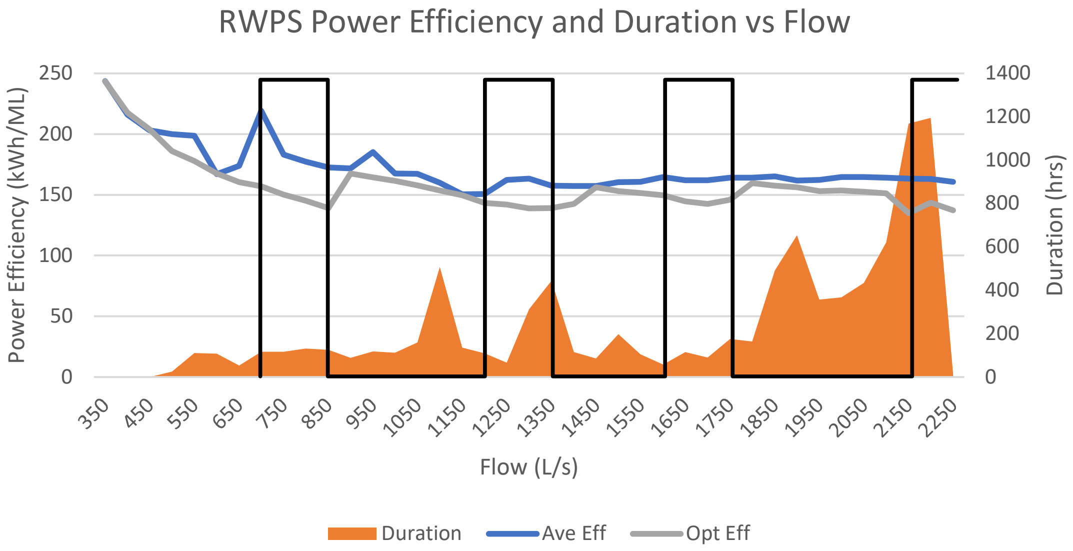


Figure 17: Preferred Flow Set Point Operating Bands for Optimised Energy Performance for a Raw Water Pump Station

4. DIGTIAL ANALYSIS AND ADVANACED AUTOMATION BENEFITS

4.1 A CASCADE OF BENEFITS

Automation improvements that result in reduced energy consumption for pump, aeration and UV reactor systems can provide a cascade of benefits.

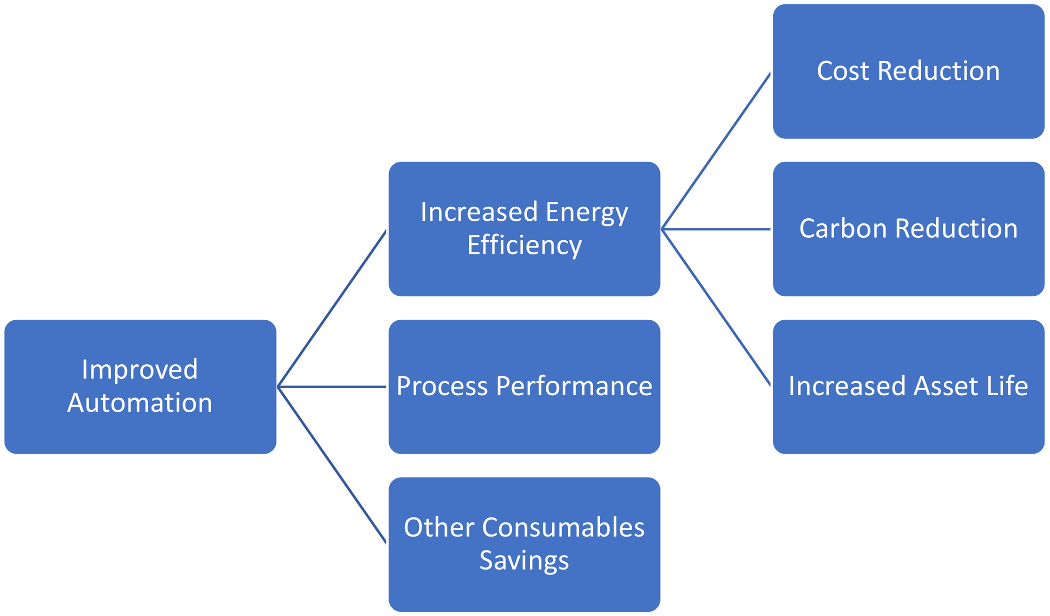


Figure 1: Benefits of Improved Automation

Improved equipment efficiency provides a triple benefit of cost savings, carbon reduction, and increased asset life. When equipment units, such as pump and blowers, operate closest to their best efficiency, they also experience reduced mechanical wear and tear.

Many of the advanced automation improvements described above in section 3.2 can also achieve benefits such as reduced flow variability, reduced chemical use, and improved performance of downstream processes.

4.2 OUTSTANDING ROI POTENTIAL

Because automation improvements are software based, and do not require purchase and installation of physical assets and interruption to carryout installations, they can be performed at low cost and in quick time. This results in very favourable returns on investment (ROI) and rapid attainment of improvement benefits.

4.3 INDICATIVE RESULTS

Table 1 below presents some indicative performance improvement results for pump, blower, and UV reactor systems where data analysis followed by automation improvements has been applied.

Table 1: Example System Savings

System Type	**Energy Savings**	**Energy Savings (MWh/yr)**	**Carbon Savings (Ton/yr)**	**ROI**
Wastewater pump station	3.5%	225	52	1-2 years
Wastewater pump station	7%	323	75	1-2 years
Wastewater pump station	7.5%	66	15	4 years
Raw Water Pump Station	15%	1,330	310	< 1 year
Treated Water Pump Station	2%	341	79	1-2 years
Aeration blowers	3%	683	159	1-2 years
UV Reactors	4.5%	293	68	1-2 years

Energy to carbon rate applied: 233.14 kg/MWh

5. CONCLUSIONS

Systems optimisation can be achieved through a combination of digital analysis and automation improvements. There is a wealth of operating data available for water and wastewater facilities, waiting for analysis to be performed.

Application of operating data analysis should be targeted for systems that are likely to present a favourable ROI. Pump stations, aeration blowers and UV reactors are high energy consuming systems that are often found to be operating below optimum performance.

A well-crafted approach that applies engineering knowledge and experience with analysis techniques can identify improvement opportunities that line up with proven advanced automation techniques to achieve improved process performance, cost savings, reduced carbon footprint, and increased asset life. This also presents an opportunity to raise the industry automations standards for water and wastewater systems to the aspiration of achieving optimum performance.

ACKNOWLEDGEMENTS

The author would like to thank Watercare Ltd for the opportunity to work on a variety of energy optimisation projects and access to historical operating data to perform analysis and implement improvements on existing automation systems.