# PERFORMANCE OPTIMISATION AND COST REDUCTION THROUGH ADVANCED PROCESS CONTROL

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**ABSTRACT**

Water service managers are often under pressure to deliver the seemingly competing objectives of both improving plant performance and reducing operational costs. This paper showcases how the application of advanced process control can realise both these objectives. Using the Te Marua WTP as an example the paper will demonstrate how Wellington Water have improved performance and reduced annual operating costs by $650k per annum.

The advanced process control functionality in real time use at Te Marua WTP includes the following:

- Predictive coagulant and polyelectrolyte dose control;
- Predictive $CO_2$ dose control;
- Automated source selection;
- Cost Measurement – Online costs, predicted cost to treat and cost sentinel to compare predicted cost to treat with actual online cost to treat;
- Online measurement of THM formation potential and HAA formation potential.

**KEYWORDS**

**Advanced Process Control (APC), Predictive Control, Opex, Process Optimisation**

**PRESENTER PROFILE**

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# 1 INTRODUCTION

In 2005 Wellington Water Ltd began a program of optimising performance and incrementally reducing costs at all their water treatment plants (WTP). The program applied advanced process controls to the existing WTP processes. The improvements ranged from the application of known relationships to more advanced chemical and physical models programmed directly into the plant control systems.

The program realised a $650k per annum reduction in total chemical costs combined with improvements in plant performance and resilience. The Te Marua WTP, which is an A1 graded plant, will be used to demonstrate the technologies applied and the benefits realised.

# 2 BACKGROUND

## 2.1 ADVANCED PROCESS CONTROL OVERVIEW

As the title implies, advanced process control (APC) is where techniques over and above basic process control are applied. Basic process control covers such techniques as flow pacing, whereby a chemical is dosed proportional to the flow, and feedback control based on proportional-integral-derivate (PID) loops whereby parameters such as pH and free available chlorine are controlled to maintain a setpoint value.

Basic process control functionality is routinely applied in WTP's in New Zealand and in most cases, it has provided significant improvements in both operational performance and operational efficiency. The Wellington Water plants were no exception in this regard with basic process control functions operating at peak efficiency.

Nevertheless, Wellington Water wished to investigate further opportunities for improving performance and reducing operating costs and so decided to invest in APC.

APC is made possible through the use of modern flexible programmable logic controllers (PLC's). APC techniques that were developed for Wellington Water plants include:

- Feedforward control;
- Realtime calculation of non-directly measured parameters -"soft sensors";
- Sequential control of logic functions;
- Model Predictive Control (MPC).

## 2.2 THE WATER TREATMENT PLANT

The Te Marua WTP is a conventional coagulation, sedimentation and filtration plant which operates on water from the Hutt River or off river storage from the Stuart McKaskill lakes. The plant uses polyaluminium chloride coagulant and a polymer flocculant aid to remove turbidity and dissolved organics. The plant has two clarifiers prior to rapid gravity filtration through coal/sand filters. The plant can also operate in direct filtration mode to achieve a higher flowrate when conditions permit. Lime and $CO_2$ is used for coagulation pH and alkalinity adjustment and sodium hydroxide is dosed for treated water pH control. Chlorine dosing is achieved through a mix of chlorine gas and sodium hypochlorite. Powdered activated carbon is dosed during episodic taste and odour events.

Prior to 2005 the processes at the Te Marua WTP were operated solely by basic control systems. This required a significant amount of operator oversight to maintain steady state performance, as setpoint control and feedback could easily result in plant quality upsets if left unattended. The cost of operating these basic systems was also poorly understood and the results of changing setpoints or adjusting control PID's were not easily discernable.

Applying an APC philosophy to the WTP required identifying improvements that would provide the greatest benefits to the following areas:

- Control reliability and treated water quality improvement;
- Chemical cost reduction;
- Transforming operations from a reactive to a proactive mentality.

The simplest and cheapest improvements were applied first and as the benefits were demonstrated more complex solutions were implemented

A number of the APC techniques that were developed were based on using UV-Vis measurements from online spectrophotometers. In 2005, these were installed at the river intake, the plant inlet and on the filtered water upstream of any post filtration chemical dosing.

# 3 APC OPTIMISATIONS

## 3.1 ONLINE COSTS

The Te Maura WTP consumes a significant quantity of chemicals annually to maintain effective water treatment and meet the requirements of the NZDWS 2005 (Revised 2008). Chemical usage and costs were estimated from bulk chemical volumes and billing data.

Month to month variations provided a general indication of where to potentially make cost savings however, this was influenced by a number of variables:

- Different operators using different operational strategies when setting chemical dose rates;
- Short, unpredictable source water quality events which dramatically increased usage;
- Differences in active ingredients of chemicals e.g. insoluble content of lime;
- Accuracy of, and discrepancies between, bulk volume measurements based on level transmitters, records from flowmeters and delivered quantities;
- Difficult to quantify costs such as sludge removal.

To increase the resolution on all these factors an online cost APC was developed. The purpose of the APC was to calculate the true 'online' instantaneous cost of operation of the plant.

The online cost for each of the chemicals was determined from calculating or deriving the chemical flowrate, or mass rate, and an operator entered bulk cost that could be adjusted like a setpoint. Where relevant, the strengths of the chemicals were also included as setpoints, such as active content of lime.

Realtime power costs were calculated from the metered total power consumption, including the power generated by a pump as turbine (PAT) facility.

Determining a real-time cost of sludge disposal was more challenging since it was a batch process. The approach taken here was to calculate a real-time solids load based on measured turbidity, dissolved organic content, coagulant dose, lime dose and powdered activated carbon dose (when used). The real-time solids load was then used to calculate a sludge disposal cost based on transport and landfill charges. The cost of the thickener and centrifuge polymer doses for the solids system were also included.

The output of each calculation is displayed as a c/m$^3$ cost rate for all the individual chemical's. Also displayed is a summed pre and post chemical cost, and the total sum of both pre and post chemical costs. This c/m$^3$ rate was combined with the total solids and power cost to create a total c/m$^3$ cost over the entire plant to provide the total online cost as shown in Figure 1.

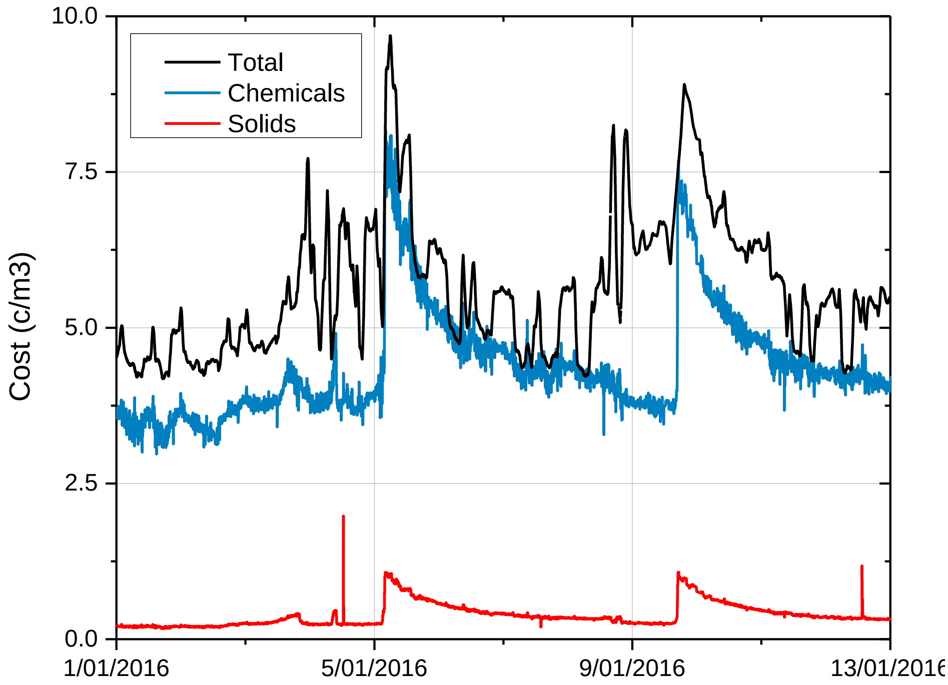


*Figure 1: Online Costs (c/m$^3$)*

The dips in total cost are the result of the pump-as-turbine system engaging when tariffs are high to generate power on site.

The instantaneous cost display provides the operators with an indication of what the actual cost of the system was at any given time. The effect of running on poor source water quality was highlighted. This led to further APC techniques being applied to automated source selection and management.

Differences were noted between the summed online costs and bulk costs and this highlighted some chemical flowmeters and mass dosing systems that needed calibration and/or maintenance.

Converting all chemical systems into a monetary value allowed a clear comparable metric between all the Wellington Water WTP's. Differences in cost, normalised for raw water quality, indicated differences in efficiency and cost effectiveness between the plants.

## 3.2 FEEDFORWARD COAGULANT CONTROL

The plant coagulant dose was originally controlled automatically using a streaming current meter (SCM). Whilst the SCM could be relied upon to cope with minor/moderate raw water quality fluctuations it had its limitations. Variations in pH affected the SCM output and, as the SCM control is a feedback system, it often failed to respond quickly enough or completely enough to rapid changes in raw water quality, thus leading to filter turbidity problems due to under dosing.

During moderate to heavy rainfall the plant operators needed to closely monitor filtered water quality for signs of deterioration, and, as the plant is only manned during the day, in the evening the operators would adjust the SCM set point to over dose in order to avoid being called out through the night as under dosing may result in having to wash all the filters to get the plant back on line. Other limitations of the SCM are that it was slow to react to improving water conditions and also that the resulting dose would often be over or under the optimum dose.

These limitations led to the installation of a feed forward coagulant dose control system based on measurements taken by an online UV-VIS spectrophotometer and exiting turbidity meter installed on the plant inlet. The UV-VIS spectrophotometer enabled both the quantification and characterisation of dissolved organic material. This information could then be used to predict the coagulant dose required to achieve treatment aims. The feed forward coagulant control system provided the following benefits:

- Chemical cost savings in both coagulant and pre-lime (approx. 20%);
- Maintaining filtered water quality under all conditions;
- Increased filter runtimes (approx. 20%).

## 3.3 POLYMER DOSE CONTROL

When using polymer as a flocculant aid it is important to use the correct dose rate to ensure that floc bridging occurs. This increases floc strength and facilitates settlement and subsequent filtration. If the dose is too low the filter will show turbidity breakthrough. If the dose is too high it causes high filter headloss and chronic issues such as mudballing. Polymer is the most expensive chemical by weight so any wastage has a significant cost implication.

Polymer dosing is typically controlled using a flow paced manually adjusted setpoint. The setpoint is determined by laboratory jar testing and often remains unchanged. In clean water conditions, this works well. However, during poor quality water events, performance can deteriorate and operators are forced to make reactive changes to the polymer dose to try to recover performance.

In order to improve the accuracy of the polymer dose, and to reduce costs to the minimum required to achieve satisfactory performance, an automated controller was developed. The polymer dose required was known to scale with an increase in coagulant dosing and therefore solids load. The solution was to create an auto polymer mode utilising a scaled (power) relationship between the feed forward coagulant dose and the polymer dose. The auto mode dose could be adjusted by +/- 20% by the operators if required. The relationship is shown in Figure 2.

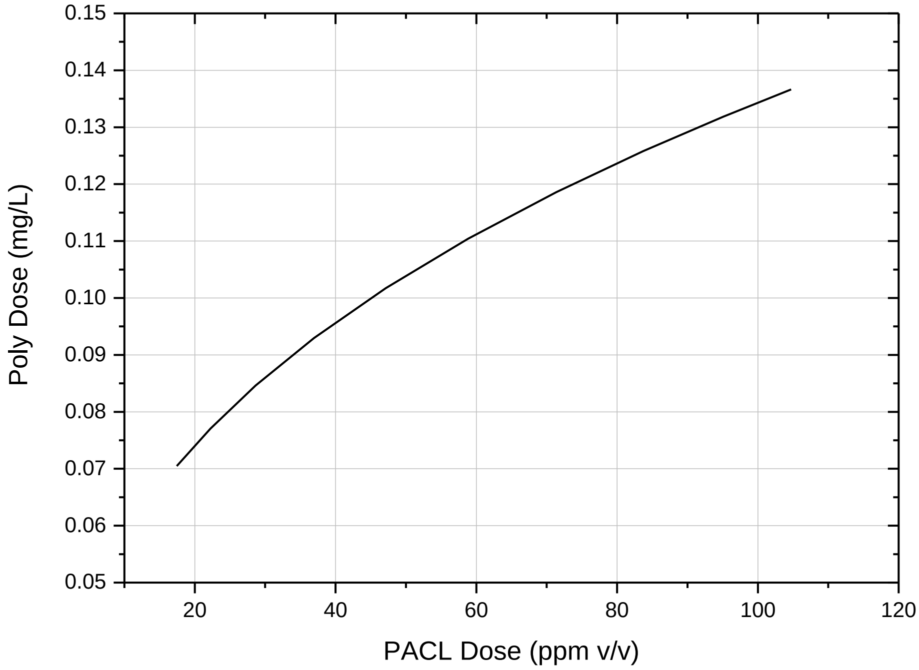


*Figure 2: Polymer Auto Dose Control*

The plants performance was improved during dirty water events, and polymer overdoses and the associated costs were reduced.

## 3.4 CLARIFIER DESLUDGE CONTROL

The two clarifiers were de-sludged on a time basis with both a timed interval and de-sludge duration. The operators would manually adjust the interval to respond to different inlet conditions.

An APC technique was developed based on the online solids load (as determined for the online cost). The online solids load was used to automatically adjust the desludge interval based on a simple $y = mx + c$ relationship.

## 3.5 PREDICTED COST AND COST SENTINEL

A predicted cost to treat algorithm was developed to facilitate source water management and to provide real time plant analytics through a cost sentinel function.

The predicted cost to treat is based on UV-Vis measurement and can be applied to both the river intake which fluctuates, and the lake source which is more stable.

The cost to treat algorithm uses the feed forward coagulant dose, the slaved poly dose, and relationships for the other chemicals based on historian data mining, with some manually input doses e.g. for PAC when used. The predicted cost accuracy is ±3%.

The accuracy of the cost prediction means that a deviation between the actual online cost and the predicted cost can be used to alert operators to something "off-normal". A deviation of ± 10% was selected to generate a warning alarm. The cost sentinel function was sufficiently accurate to determine changes in delivered chemical quality (e.g. lime and coagulant) and was used as a trigger to instigate further investigations and dialogue with chemical suppliers.

The predicted cost to treat function also enables the plant PLC to make cost based decisions on which source to use. When the predicted cost to treat river water becomes higher than the cost to treat lake water the plant automatically switches to lake supply.

## 3.6 FEEDFORWARD ALKALINITY CONTROL

Alkalinity is important for maintaining long term integrity of concrete lined steel pipes in the reticulation system. When alkalinity is too low the water can be sufficiently aggressive that calcium carbonate in the concrete will leach out and cause degradation of the concrete lining. Wellington Water had previously concluded, from a long-term study, an optimum alkalinity level of 22-25 mg/L as $CaCO_3$ at a pH of 7.8.

The concentration of the treated water alkalinity is the net result of the raw water alkalinity and the doses of a number of chemicals used at the plant. The river alkalinity at Te Marua is generally low so carbon dioxide dosing is used to force the pre-lime dosing system to maintain coagulation pH, which adds alkalinity.

The $CO_2$ dosing system was operated at a fixed dose rate despite variance in both raw water alkalinity and in the applied chemical doses. The resulting treated water alkalinity was therefore highly variable.

Controlling the treated water alkalinity to a setpoint required the $CO_2$ dose to be automatically controlled. In order to determine a $CO_2$ setpoint the impact of all chemicals that could impact the pH and alkalinity was modelled. The raw water alkalinity also had to be determined.

Online alkalinity instruments were trialed on the plant inlet but were found to be difficult to maintain so a relationship between the conductivity, pH and alkalinity was determined using laboratory samples. Since pH and conductivity were measured online an alkalinity "soft sensor" could be developed.

A physical chemistry model was developed and programed into the PLC which used the raw water alkalinity soft sensor, predicted dose setpoints, and solvers to determine the resulting lime and sodium hydroxide dose requirements. From this a $CO_2$ dose setpoint is derived that solves to achieve the treated water alkalinity setpoint, within a limited $CO_2$ dose band.

Although the model was complex to program into the PLC, when it was enabled it allowed the plant to reach a targeted treated water alkalinity within +/- 2mg/L regardless of raw water conditions or any other factors. A treated water alkalinity analyser was used to verify the model.

## 3.7 CHLORINE DEMAND AND THM/HAA FORMATION POTENTIAL

An extensive laboratory test program was used to develop UV-Vis based parameters for 24h chlorine demand and for total trihalomethane (TTHM) formation potential and Haloacetic Acid (HAA5) formation potential.

The UV-Vis parameters were accurately calibrated accurately against the laboratory measurements as shown in Figure 3, 4 & 5.

This allowed online measurement of these parameters in both the source water and the filtered water.

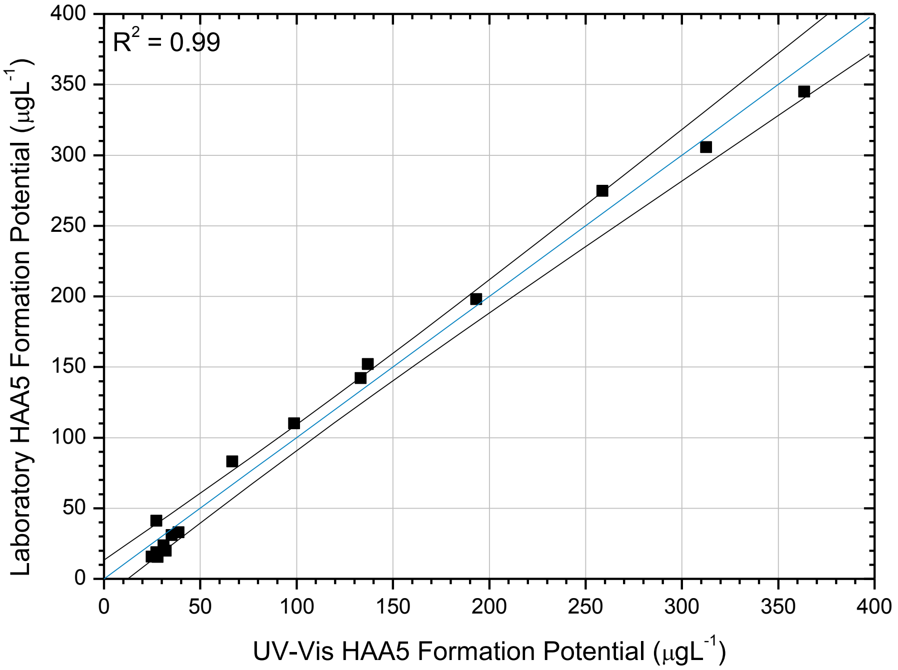


*Figure 3: HAA5 Parameter Regression*

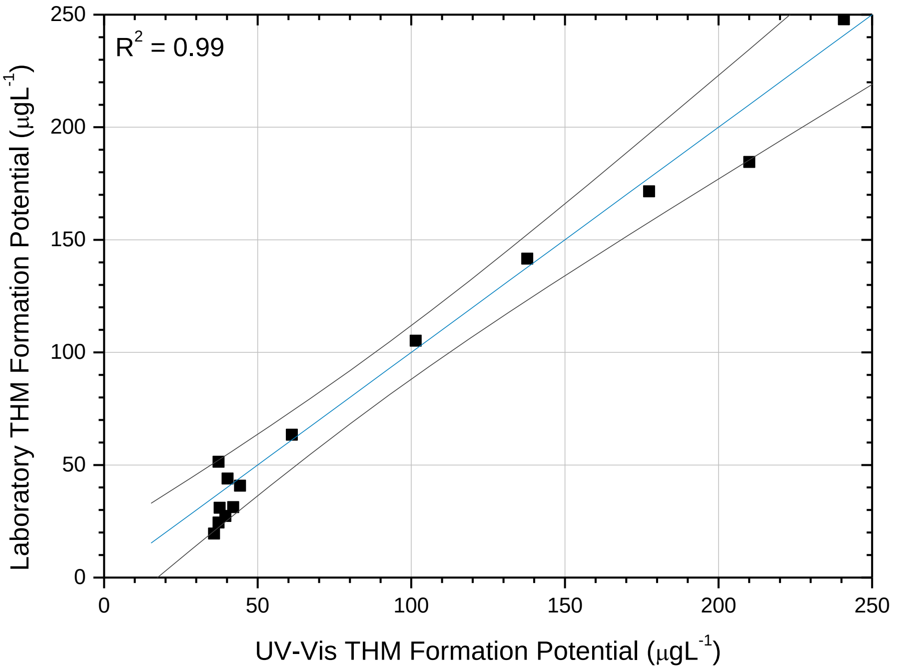


*Figure 4: THM Parameter Regression*

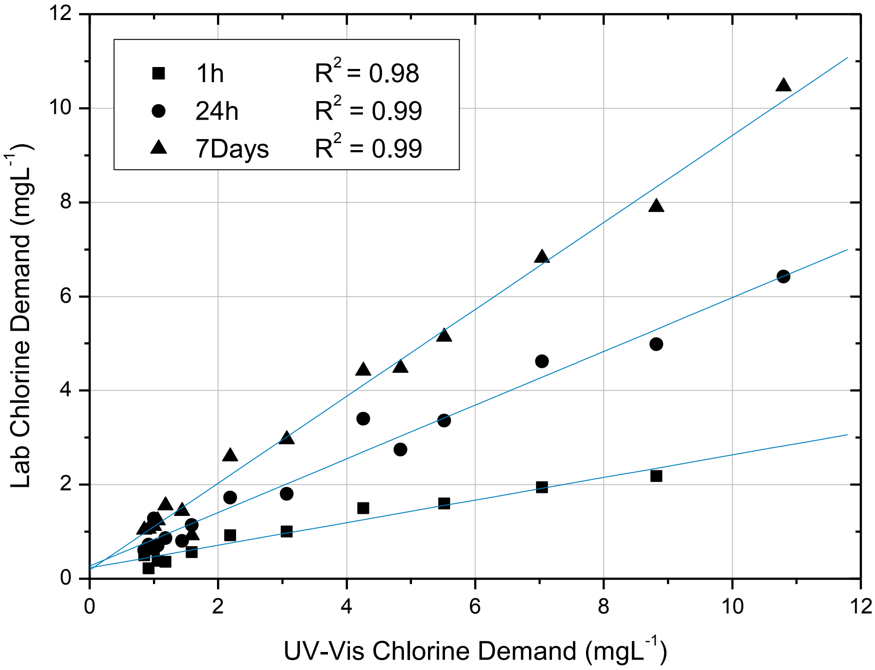


*Figure 5: Chlorine Demand Parameter Regression*

## 3.8 ENHANCED ORGANICS REMOVAL

An online measurement of chlorine demand, TTHM and HAA5 formation potential allowed for further optimisation of organics removal at the plant.

A coagulant trim function was introduced whereby the feed forward coagulant dose was adjusted to maintain an operator selectable parameter (TTHMFP, HAA5FP, UV254 & $Cl_2$ demand), within defined limits, as measured on the filtered water. This ensured that organics removal for the target parameter was optimised in the most cost-effective manner by increasing or decreasing the coagulant dose as required. For example, the inlet THM and HAA formation potential shown in Figure 6 & 7 is controlled to maintain an outlet concentration within an operator selected band whatever the conditions.

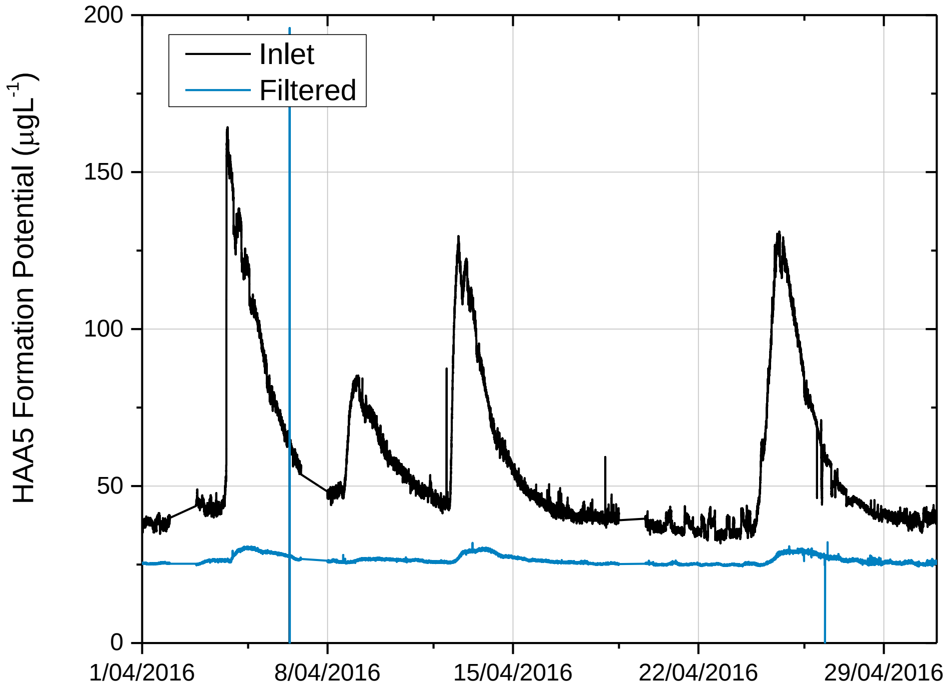


*Figure 6: HAA5 Formation Potential Removal*

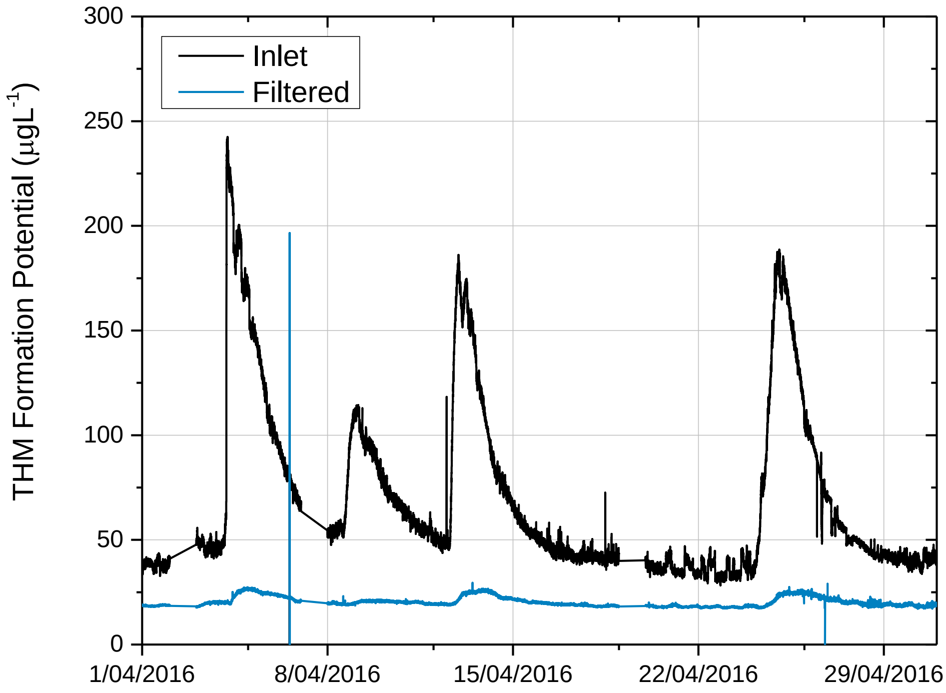


*Figure 7: THM Formation Potential Removal*

# 4 CONCLUSIONS

The application of advanced process control (APC) has been shown to provide improvements in plant performance and resilience whilst simultaneously making large reductions in operating cost illustrated by the drop in bulk chemical usage shown in Figure 8.

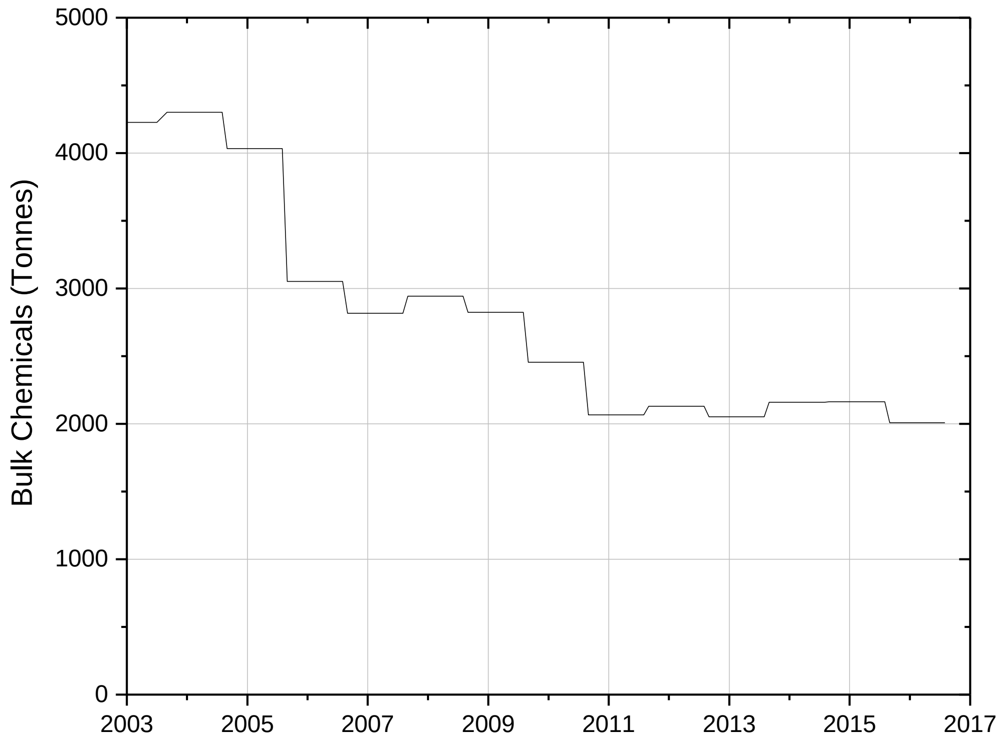


*Figure 8: Total Bulk Chemical Use*

Some of the APC techniques presented in this paper can be applied to any treatment plant without requiring specialist instrumentation or indeed specialist engineering input.

Other techniques presented do require additional instrumentation and automation but as Wellington Water have shown the return on investment for APC can be extremely rapid.

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