PROJECT WAI TAATARI – IMPLEMENTING THE NEW PLYMOUTH WWTP DESIGN-BUILD UPGRADE

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ABSTRACT

MWH Global provided design services for the Fulton Hogan upgrade of the New Plymouth Wastewater Treatment Plant known as Project Wai Taatari.

The main focus of the upgrade was to achieve efficient aeration treatment and provide additional capacity through asset optimization and treat flow and load for a 2040 design horizon. The upgrade converted existing Carousel-process aeration basins (race-track flow) into plug-flow biological nutrient-removal processes.

The process design in combination with high-speed centrifugal blowers, fine bubble diffusers, and aeration control package was used to reduce aeration power usage (on energy to flow ratio basis) by 25% while providing improved treatment of the incoming wastewater.

This paper describes how MWH's design approach led to improved plant performance, energy savings for New Plymouth District Council and provided a successful outcome for Project Wai Taatari.

KEYWORDS

Design Build, Wastewater, Biological Treatment, Asset Optimization, Energy Efficiency, Power Consumption.

1 INTRODUCTION

In 1984 twin Carousel aeration basins were built to service wastewater entering the New Plymouth Wastewater Treatment Plant (WWTP). The wastewater moved around the basins in a race-track flow pattern and the basins were aerated by surface mounted aerators. That WWTP itself, through good management and operation, provided a good level of treatment and the effluent quality generally meet consent requirements. Twenty-five years later, as the WWTP approached its hydraulic and biological design horizon New Plymouth District Council (NPDC) requested for tenders for Project Wai Taatari: a design-build aeration upgrade of the plant to meet the new 2040-based design horizon.

While there were a number of the specific requirements the two key items for the upgrade were:

- Ability to achieve treated wastewater quality standards.
- Power efficiency

Fulton Hogan were the successful tenderer for the works supported by MWH Global as the designers. The MWH-based design utilized high speed centrifugal blowers, fine bubble diffusers and a new process configuration. The complete supply of the aeration system, from diffusers and dissolved oxygen (DO) probes and control system through to blowers was supplied and installed by specialist subcontractors.

2 DESIGN – VALUE ENGINEERING

The design and build process allowed value engineering and innovation to be included in the process. The following elaborates some of the elements from this project.

2.1 PLANT FLOW REQUIREMENTS

The tender requirements for the plant were to allow a maximum full flow to treatment of up to 880 L/s with flow in excess of this sent to a bypass. The indicative future peak wet weather flow was estimated to be 1220 L/s (1095 L/s from the New Plymouth catchment and a further 125 L/s from the Waitara catchment) and the difference of 340 L/s would need to be diverted, via chlorinated bypass, around the WWTP and to the outfall discharge.

MWH reviewed and developed a HADES hydraulic model (MWH-developed hydraulic analysis package) through the aeration basins and clarifiers to the point of discharge. The model generated indicated that, through two bioreactors and three clarifiers the plant would be able to pass the full 1220 L/s (subject to relatively minor modifications). Based on this assessment the WWTP would not have to bypass any flows this would significantly reduce the risks around bypassing part of the raw wastewater flow and mixing for chlorination and discharge.

2.2 PROCESS DESIGN

Each aeration basin was re-configured to a three stage biological nutrient removal process consisting of anaerobic, anoxic and aerobic compartments. Nutrient removal itself was not a consent-required condition but the biomass generated in these plants help to promote sludge settleability. To achieve this configuration concrete partition walls were constructed within the Carousel racetrack. These walls changed the plant flow from looping around the plant (race-track design) to being plug flow. Figure 1 shows the reconfigured plant layout, the anaerobic zone is shaded in red, anoxic in green and the aerobic portion in stripes.

Photograph 1: Construction of the partition wall in Bioreactor 2

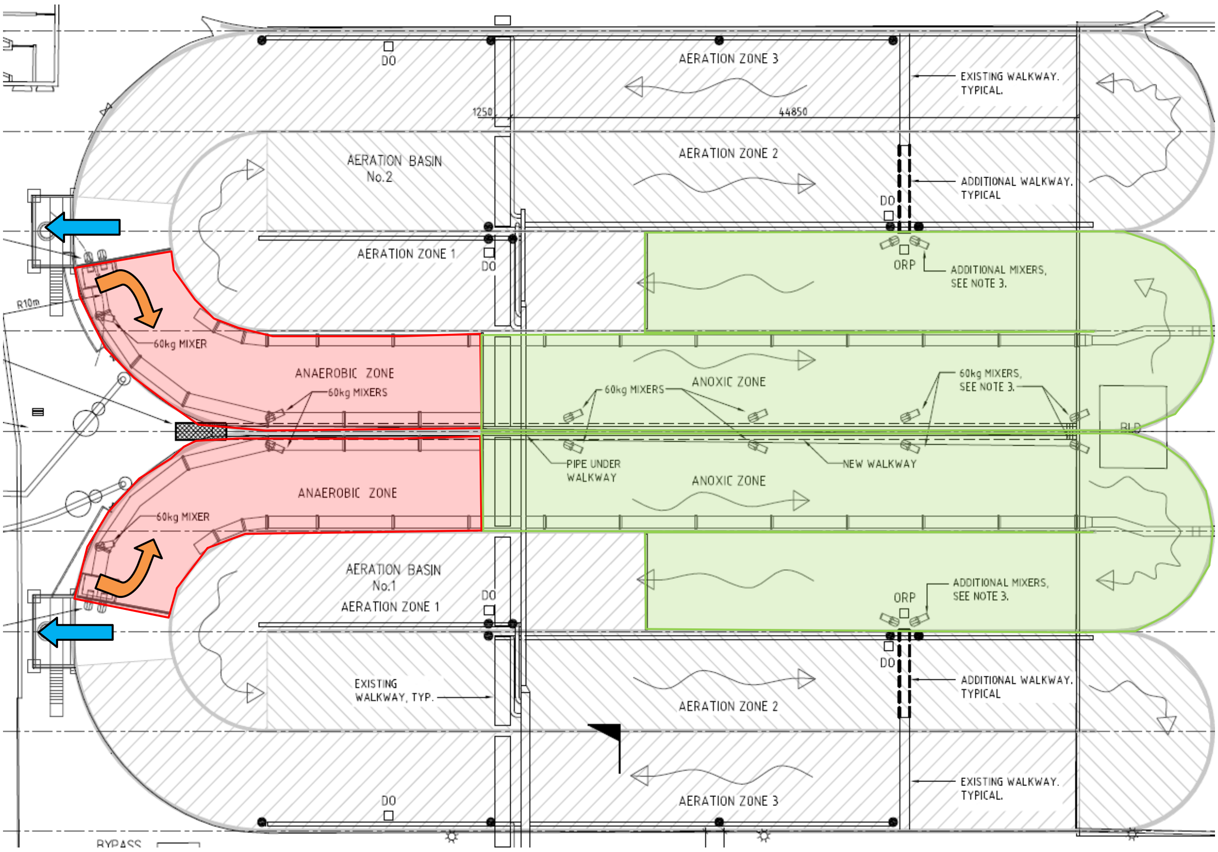


Figure 1: New plug flow layout of bioreactors at the New Plymouth WWTP

The MWH process design used the information on the existing WWTP and historical influent wastewater characteristics to generate a process model. This modelling was carried out using the BioWin™ software. The model was used to predict process performance throughout the bioreactor tanks based on the proposed layout.

The anaerobic zone receives the return activated sludge (RAS) and screened raw wastewater. The flow then passes forward into the anoxic zone where a nitrate-rich recycle mixes with the carbon-laden incoming flow. The combined mixed liquor then finally passes into the aerated zone where the load is aerobically treated by the biomass.

The anaerobic zone was included as a selector to promote floc-forming bacteria to improve the settling characteristics of the biomass and reduce the likelihood of filamentous bacteria proliferating while the anoxic was used to promote denitrification for efficiency and process stability. The aerated zone was designed to have a tapered aeration profile: higher oxygen concentration at the front of the zone reducing as it passes through to the end of the bioreactor.

The effluent quality targets for the process were set based on having all plant available and achieving a 95th percentile 25 mg/L limit for both suspended solids and the 5-day biological oxygen demand (BOD_5) concentrations. In addition to this the plant should be able to remove at least 50% of the incoming nitrogen.

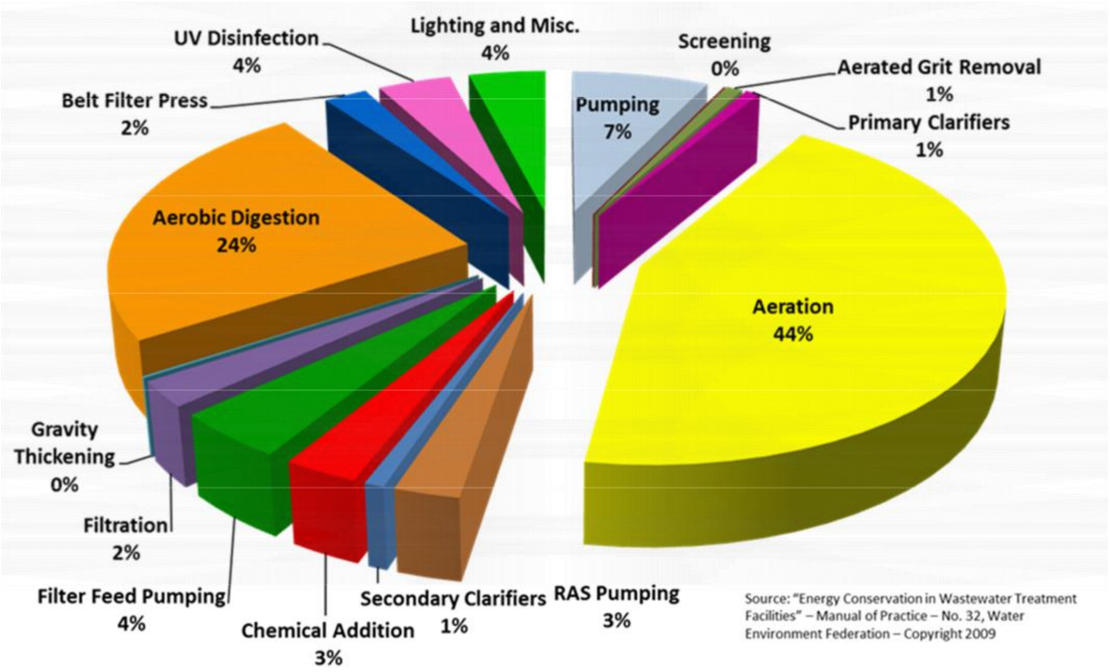
Three effluent quality targets for the process were set for the upgrade. These were to:

- Meet a 95th percentile suspended solids limit of less than 25 mg/L;
- Meet a 95th percentile 5-day biological oxygen demand (BOD_5) limit of less than 25 mg/L; and
- To remove at least 50% of the incoming nitrogen load.

The suspended solids and BOD_5 represent the resource consent conditions for discharge. These were subject to having all the plant processes available. The consent allows for a period of 14-days per year where the consent conditions are relaxed (110 mg/L for suspended solids and 130 mg/L for BOD_5)

2.2.1 ENERGY EFFICIENCY ADVANTAGES

There were a number of the process decisions that had an effect on the energy efficiency of the WWTP. Figure 2 shows a textbook split of energy usage for aeration at 44% of the overall energy for the entire plant. This means that energy savings within the aeration can have a significant effect on the energy usage for the entire plant.



Source: "Energy Conservation in Wastewater Treatment Facilities" – Manual of Practice – No. 32, Water Environment Federation – Copyright 2009

Figure 2: Estimated Energy Usage for a 20 ML/d Nitrifying Activated Sludge Facility (Source: "Energy Conservation in Wastewater Treatment Facilities" – Manual of Practice – No 32, Water Treatment Federation – Copyright 2009)

The tapering of the oxygen concentration was designed to improve performance and consequently improved energy efficiency through reducing the quantity of excess air required to aerate to a high concentration and through reducing the amount of air recycled back into the anoxic zone.

Fine bubble diffusers were installed in each of the bioreactor tanks. Fine bubble diffusers have a better oxygen transfer efficiency (rate at which air delivered to the process is transferred into the water) than the old surface aerators that they replaced. This means that the amount of energy required to provide the same amount of air would be greatly reduced.

MWH assessed the air and blower requirements using historical data extrapolated to the 2040 design horizon. The oxygen demand profile to be satisfied by the blowers is shown in Figure 3. The aeration system was designed to target 2040 Peak Week loads in rather than Peak Day which would have seen a considerable increase in cost to accommodate the additional aeration capacity required to meet that demand whilst providing only an infrequent and marginal benefit to treatment performance.

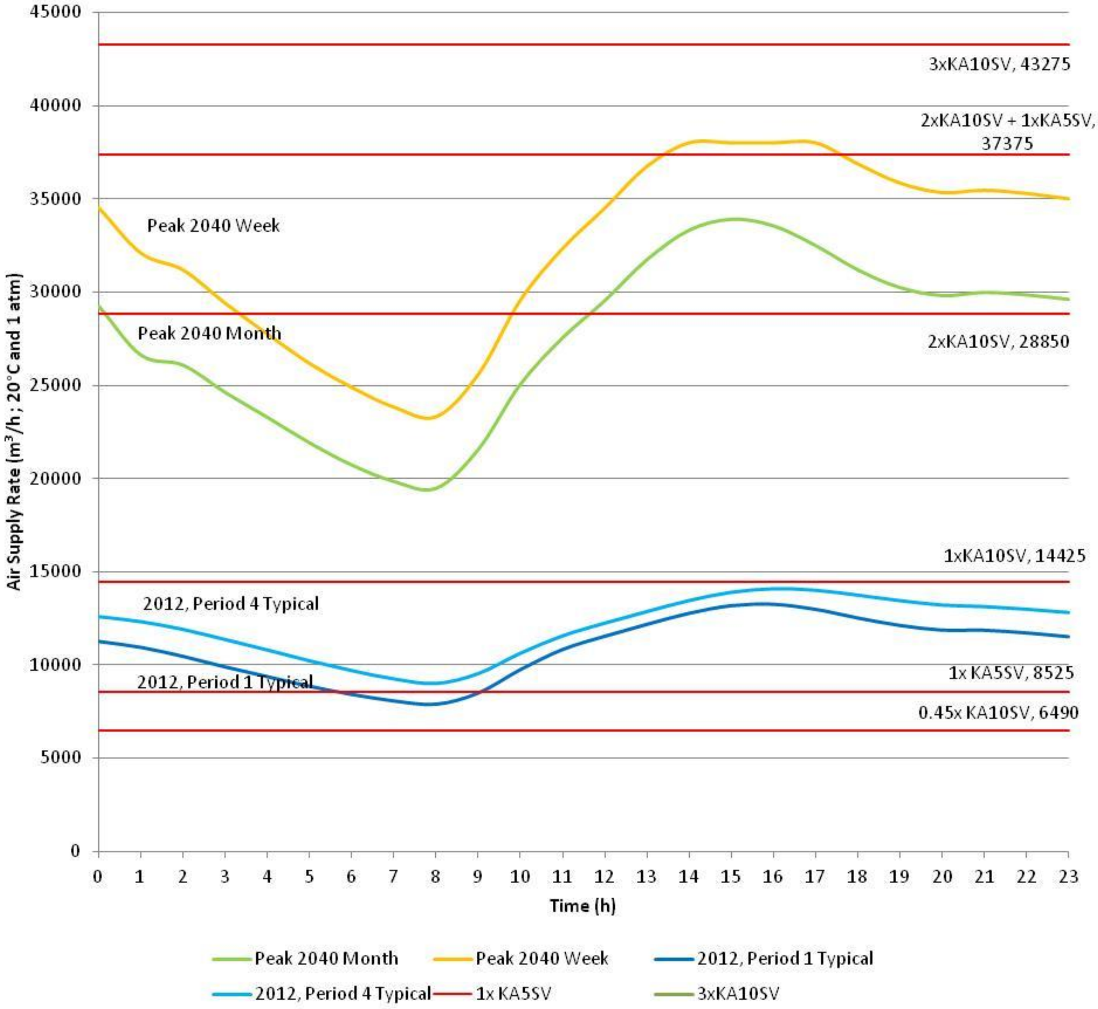


Figure 3: Model predicted daily diurnal profiles for air supply requirements

These predicted airflow requirements were also used in the sizing and selection of the blowers. Siemens provided three large STC-GO-10SV-GK200 (KA10) centrifugal blowers and one smaller STC-GO-5SV-GK200 (KA5). This combination was selected so that any three of the four blowers would be capable of supplying the maximum required air supply rates at the design horizon allowing one to be unavailable and still meet airflow requirements. The smaller blower was selected to provide a greater flexibility of operational options to efficiently achieve airflow requirements and turndown.

Photograph 2: Newly installed Siemens blowers

The aerated fraction of each bioreactor was broken down into three separate aeration zones. Air supply to the diffuser grids in each of these zones was controlled via a standard Siemens' blower control package to meet DO set-points. The control package uses a most-open-valve control philosophy and pressure control loops to efficiently manage blowers to meet demand requirements. By breaking the bioreactor down into separate zones and controlling the number of blowers that supply the air, additional aeration efficiency was achieved.

Through tracking the DO concentration throughout the day and matching the airflow to meet requirements it is also possible to ensure that treatment levels can be met even at unexpected high loadings and over-aeration avoided at lower than expected loadings.

Nitrification, conversion of nitrates into ammonia, results in a significant consumption of oxygen. For every 1 kg of nitrogen converted to nitrate, 4.57 kg of oxygen is required. Without a denitrification step, this oxygen bound in the nitrates would simply be discharged with the treated effluent. With the use of an anoxic recycle, the nitrate-based oxygen is returned back to the anoxic zone where it is then used (in the absence of other oxygen sources) along with some of the carbonaceous organic material by specific microorganisms. The nitrate molecule is stripped of its oxygen and turns into nitrogen gas and is released into the air resulting in overall nitrogen removal from the process.

2.2.2 ASSET OPTIMIZATION - REUSE OF EXISTING PLANT

The reuse of existing plant within the design and build framework helps to reduce the cost for both NPDC and the contractor.

- In this aeration system upgrade, the existing biological tanks as well as the clarifiers were reused, with baffling and internal walls installed in the tanks to create the plug-flow bioreactors and modifications to the inlet structure of the clarifiers to allow full flow to pass through them.

- MWH assessed the capacity and suitability of the existing RAS pumps for sludge withdrawal from the clarifiers. The pumps were found to meet requirements under a new, flow-proportional pumping regime but this required extensive reconfiguration of the pipework within the pump station along with the addition of control valves and flow metering,

- Aeration efficiency is also maximized by maintaining Bioreactor water levels as high as possible during normal. The bioreactor outlet weirs however need to be lowered in order to pass peak flows. It was originally proposed to achieve this with a pair of new 5m wide weir penstocks; however the existing radial weirs were also identified as potentially suitable for reuse. Through parallel design and construction programming and fast tracked refurbishment, the existing weirs were able modified and reused whilst avoiding significant structural modifications. New actuators provided the improved positional control and diagnostics to drive the hydraulic flow through each bioreactor

- The existing clarifier-feed flow splitter box was found to be adequate for future requirements for splitting the flow of mixed liquor from the two bioreactors to the three clarifiers. Adjustment of the weir plates within the splitter box was required to allow full plant flow to pass through.

2.2.3 DESIGN WORKSHOPS

As part of the design-build process, HAZOP and Safety in Design workshops were run. These workshops added value to the project as, during these interactive meetings, the Council and contractor teams were able to raise and discuss design issues apparent in the process and make allowances or changes to the design to improve the operability and functionality of the design and manage risk.

2.2.4 METHODOLOGY OF IMPLEMENTATION

Construction and upgrade by Fulton Hogan was carried out while keeping as much of the live plant operational as possible. While the first aeration basin was taken offline, flow was diverted to the second aeration basin. Not all flow could be treated by a single basin and the balance was bypassed to disinfection and outfall. The clarifiers were taken offline sequentially for modifications to the clarifier inlet structures to be made.

After installation and clean-water testing of the equipment in Bioreactor 1, wastewater was finally introduced. Bioreactor 1 operated in tandem with Aeration Basin 2 during the commissioning period. This had its own set of issues as modifications to RAS pump station had not yet been implemented and there was mixing of biomass between the two processes. The Clarifier RAS return was identified as a restriction. The existing operation was for the RAS pumps to run at a set fixed speed, this caused biomass to build up in the clarifiers during higher flow periods and then return to the aeration basins as flows dropped. Upgraded operation would be for the RAS pump flow to be set proportionally based on incoming plant flows. This was identified as a risk that was closely monitored during this period to reduce the likelihood of solids discharge. Following completion of Bioreactor 1 commissioning the remaining aeration basin was taken offline and upgrade undertaken.

Photograph 3: Google Earth view of the New Plymouth WWTP during installation of diffuser grids on Bioreactor 1.

Significant parts of the pipework (including for the RAS pump station and blower header pipes) were prefabricated onsite prior to installation to limit shutdowns of the associated processes. Fulton Hogan worked closely with NPDC operations staff to identify windows of opportunity for plant to be taken offline and how services could be largely maintained during these periods.

Following commissioning of Bioreactor 1, the remaining upgrades were undertaken. The operational plant was reduced to one bioreactor and a single clarifier as modifications were made to the splitter box. Following installation, modification and clean-water testing, Bioreactor 2 was brought online. Fulton Hogan then operated the plant through the commissioning period.

3 BUILD – OBSERVED TREATMENT OUTCOMES

The upgraded plant has now been in operation for 18 months and the following section outlines some of the benchmarked outcomes measured over this period.

3.1 ENERGY BENCHMARK

Table 1 below shows the average daily power usage for the New Plymouth WWTP. The plant was in various stages of construction and upgrade through 2013 and full operation by the Council was resumed in 2014. Flows from the Waitara catchment were introduced in October 2014 and this increased the energy requirements at the plant. The increase in energy requirement shown for September 2014 was caused by an industrial discharge to network (this is discussed later). This includes all power usage measured at the blower building (this includes the milliscreens) and this represents 60-70% of the current total site requirements (the 2014/15 financial year ending in May, had a total energy use for the site of 3,900,000 kWh). With such a large proportion of the overall site power requirement, it emphasizes how significant aeration efficiency is to NPDC is to a whole.

Table 2 shows the flows to the plant. These have increased through growth and connection of the Waitara stream. Flows over the previous 12 months have been 8% higher than the corresponding 2010-2011 period. The blower energy usage has reduced by 25% when compared to the 2010-2011 period. Over the past 12 months a rate of 0.31 kWh/m³ has been measured for the plant, compared to 0.42 kWh/m³ prior to the upgrade.

Table 1: 2010-2015 Average Daily Power Usage (kWh/d)

Year\Month	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**Annual Average**
2010		8387	9273	9614	9392	9661	9210	8966	9081	9372	9412	9118	9268
2011	9134	9296	9290	9626	9194	8803	8825	8723	9160	9182	9502	9696	9201
2012	9511	9349	9425	9184	9366	9639	9381	9514	9568	9309	9094	5910	9334
2013		437	2281	3978	2907	1849	2086	2298	1674	1742	1727	1824	2173
2014	2902	6941	6574	6175	6480	6604	6359	6618	8074	6767	7751	8115	6605
2015	8721	7174	7367	6817	7306	6670							7352

Table 2: 2010-2015 Average Daily Plant Flows (m³/d)

Year\Month	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**Annual Average**
2010	18501	19375	18401	17478	22261	31086	24700	25760	29862	24300	18139	19817	22481
2011	19452	17905	19270	19547	24772	31995	27749	21392	19789	26643	24381	29146	23545
2012	27492	21718	24414	20675	20386	23451	27083	30495	24526	21792	18854	20383	23466
2013	18645	17449	16420	19750	26433	27528	22939	20103	22947	27401	21667	23105	22060
2014	21199	17809	17086	19412	21799	23178	24012	23252	20515	22341	24742	22768	21535
2015	19405	22035	20869	28874	32582	35960							26633

3.1.1 DIURNAL PROFILE

A comparison of the diurnal power draw profile from before and after the upgrade is shown in Figure 4. Both profiles dip in the early morning as the plant responds to the drop in load overnight but as the load picks up through the morning so does the power drawn. Whereas the 2012 draw plateaus at around 400 kWh (restricted by the capacity of surface aerators), no such plateau is reached in 2014. The improved aeration efficiency means that the power drawn is less and the additionally aeration capacity means that the blowers would be able to supply additional air to the WWTP if required and a higher quality of treatment was provided.

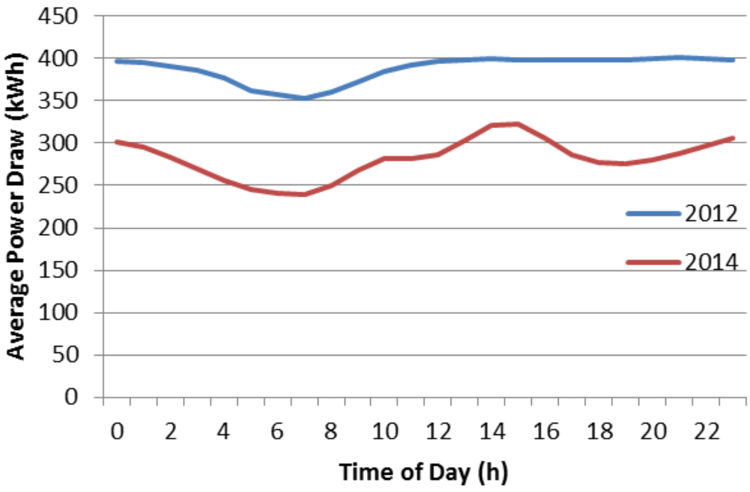


Figure 4: Composite Diurnal Power Use Profile (Source: October 2012 and October 2014)

Monitoring of the aeration system (blower operation and power requirements) has identified atypical discharges to the system which can be traced back to tradewaste discharges. In September 2014 an oil discharge from an industrial area was dumped into the sewerage network that feeds the WWTP. Historically, the existing aeration system would not have been capable of supplying sufficient air to the process to treat such a discharge. To meet the aeration requirements all blowers operated for a period. This is reflected in the power draw shown in Figure 5. The diurnal variations are still evident but there is a massive spike caused by the discharge that increases hourly energy requirements from 200-300 kWh up to 700-800 kWh. The residual is gradually processed and after 10-days a more normalized power profile resumed. Importantly over this period the WWTP continued to treat wastewater to the required effluent quality standards and no long-term disruption to processes was experienced. This improved visibility of weekly patterns has led to an improved management of trade waste customers and a reduction in short duration peak loads that had previously been missed. Shifting these peak loads improves energy efficiency as tariffs for energy-use vary according to the greater Taranaki-network usage.

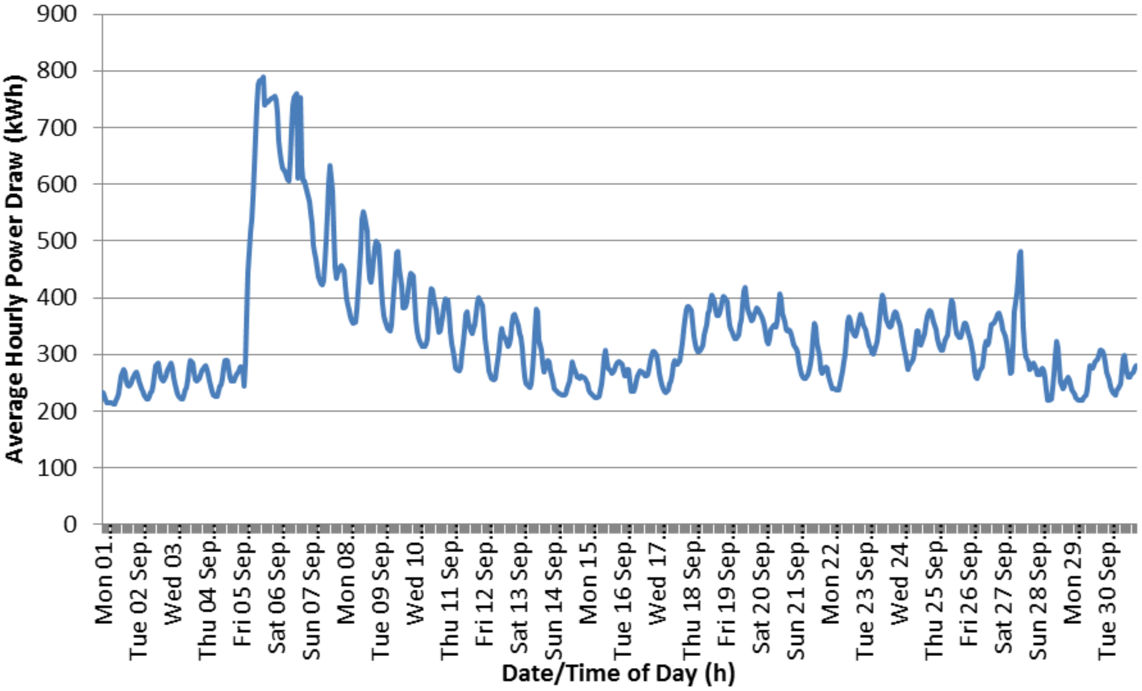


Figure 5: Average Hourly Power Draw Following 2014 Oil Discharge

3.2 EFFLUENT QUALITY BENCHMARK

With both bioreactors in service, the bioreactors have been able achieve effluent solids concentration of less than 10 mg/L, shown in Figure 6, and BOD_5 concentrations of less than 5 mg/L, shown in Figure 7, on a consistent basis. The exception to both of these was during mid-Jun 2015 when one of the bioreactors was taken offline for maintenance purposes. This resulted in elevated effluent concentrations during this period which are allowed for under the consent conditions for a bioreactor out of service (up to 110 mg/L suspended solids and 130 mg/L BOD_5).

Figure 8 shows the ammonia and nitrate concentrations measured in the final part of the aerated zone in each bioreactor. Nitrogen from this zone is either passed through to the clarifiers and discharged or sent via recycle back into the anoxic zone for denitrification. Ammonia concentrations are below 1 mg/L in both reactors while the nitrate concentration trends at 6 mg/L. Influent total nitrogen concentrations are not measured, but based on the influent ammonia of 30 mg/L can be estimated to be around 40-45 mg/L. This means that the system is removing 85% of the nitrogen entering the plant which is well above the Contract requirement of 50% total nitrogen removal and a demonstration of the focus on aeration efficiency.

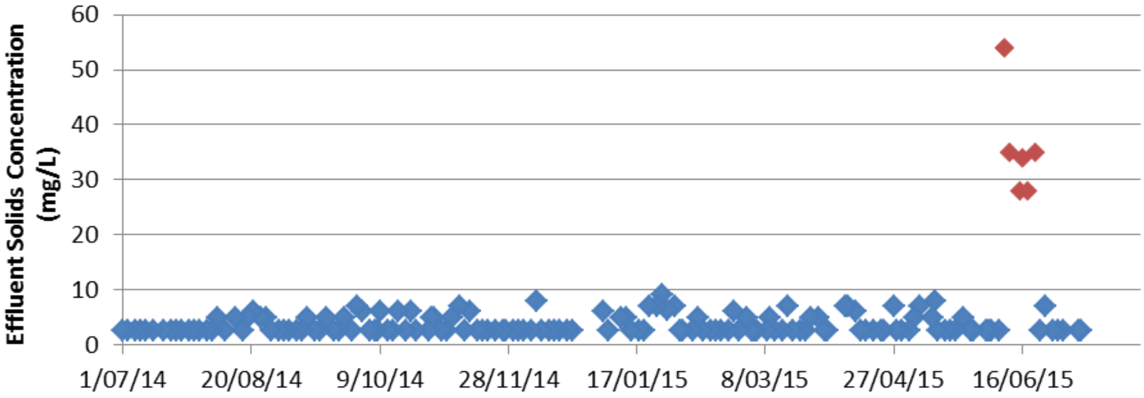


Figure 6: Composite Sample Effluent Solids Concentration

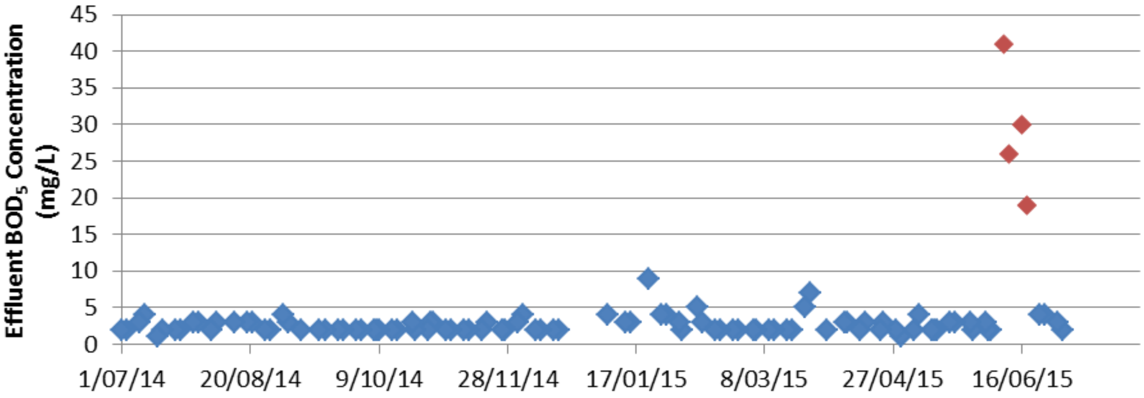


Figure 7: Composite Sample Effluent BOD$_5$ Concentration

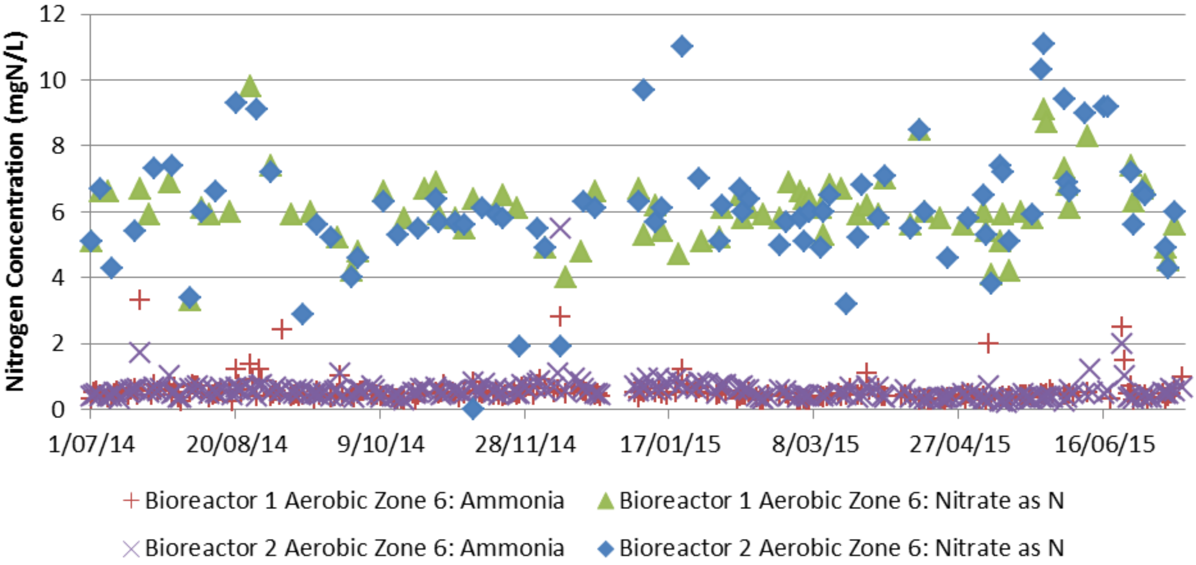


Figure 8: Bioreactor End-Zone Nitrogen Concentrations

4 CONCLUSIONS

The design-build aeration upgrade of the New Plymouth WWTP has successfully achieved the two key parameters. The upgrade to the WWTP was required to implement energy efficient concepts into the design and to meet treated wastewater quality standards.

The quality of effluent produced by the WWTP shows that under normal operation the effluent quality meets the discharge quality requirements. Typical discharge solids concentrations were less than 10 mg/L and BOD_5 concentrations less than 5 mg/L. Nitrogen removal of 85% of the influent nitrogen is significantly improving the quality of the treated wastewater while reducing the airflow requirements.

Through the use of high-speed centrifugal blowers, fine bubble diffusers and control package both the efficiency and the capacity of the aeration system for the plant was increased. This has resulted in a rate of 0.31 kWh/m^3 and a 25% reduction on 2010 power requirements with a significantly increased treatment capacity and effluent quality. The system itself has also provided the ability to monitor and record when industrial discharges affect the plant. The direct benefit of more efficient aeration has resulted in an $80,000 saving in the past year when compared back to the equivalent 09/10 period. In addition the increase in process visibility and other benefits derived from the upgrade have resulted in a real reduction in electricity spend for the whole site in the order of $150,000 when compared to the same spend in 09/10.

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