Innovative NZ Aeration system enhanced Ammonia removal and WWTP efficiency

T Okan Dcm Process Control & J.W.Nagels IWA, Aquaero Pty Ltd

ABSTRACT

A case study on the Waitomo Village oxidation pond system showed significant improvement in treatment capability by the installation of a surface based horizontal venturi fine diffusion aeration system called the Aquarator. The pond performance was studied using an online water quality monitoring station Inlet and outlet flows were measured and mass loadings computed for COD, CODf, Tss Nitrate and Ammoniacal Nitrogen. Independent laboratory analysed manual samples were utilised to verify the monitoring station data. The Aquarator was deployed for 8 months in the Waitomo oxidation pond system beginning Nov 2015. Prior to 2015 the treatment system had failed compliance (exceeding 10mg/l) on Ammoniacal Nitrogen for 9 years. The Waitomo oxidation pond system was originally refurbished to its existing form in the 1950's. Due to expansion of tourism operations the systems is now expected to treat up to a peak of 4000 people per day. The system was never designed for that loading.

The study clearly demonstrates a significant removal of ammonia. An increased load treatment capacity within the existing plant footprint is now achievable with compliance.

In addition, this field study demonstrates the ability of the Waitomo oxidation pond treatment system to be able to comply with a regional council directive to reduce compliance levels by 30% over the next ten years. In addition, the Aquarator installation can accommodate an increase in tourism growth without having to face an expensive upgrade placing a financial burden on the Waitomo Rate Payer.

Keywords

Upgrading Oxidation pond, Innovative aeration, Ammonia removal.

.

1.0 Introduction

The Waitomo Waste Water Treatment Plant (WWTP) consists of an influent pond (Pond one) secondary pond and a sludge drying area. (Photo 1)

The predominant source of ammonia in the existing influent is from the toilet facilities at the Waitomo caves tourist adventure operation. Other significant contributing sources include, sewage from township, hotel, backpackers and motor camp accommodation including food processing facilities effluents and cleaning and laundry products from accommodation facilities

A 2kWh surface brush aerator had been installed in the influent pond for the last 9 years. The pond had failed to reach consent levels on a variety of parameters the most consistent being a failure to reach Ammonia compliance of 10mg/l (sometimes exceeding 30 mg/l) even after the pond was desludged. Our approach to remedy this noncompliance was to install an Aquarator unit into the primary pond.

We monitored the input and output of Pond One for a defined period of 8 months and determined the enhanced pond efficiency.

2.0 Methods

A portable water quality monitoring station (PQMS) made by DCM Auckland containing a UV- Vis spectro::lyser, range 200nm to 720nm. (s::can Vienna Austria). A proprietary built sample delivery unit (SDU) (DCM Auckland). A pH probe (s::can Vienna Austria) A con::cube controller (s::can Vienna Austria) with remote modem connection was installed sequentially on the effluent discharge for seven days June 1 to June 7 and the influent manhole of Pond One (June 8-June 30) Influent aliquots delivered by the SDU were supplied to the PQMS. Measurements were taken by the spectro::lyser every two minutes and a proprietary software (ana::pro) inferred values for nitrate (NO_3), Chemical Oxygen Demand (COD) and Chemical Oxygen Demand filtered and flocculated (CODf) and suspended solids (TSS) and Biological Oxygen Demand (BOD_5). In addition, spectral fingerprint data was examined by propriety software The Iceberg analysis (DCM Auckland) for variations to the normal spectra for any known aberrant compounds that might provide toxicity or inhibitory effects on the biomass. Samples were collected intermittently from the SDU discharge line and sent for independent laboratory analysis to validate the levels registered in the parameter files. Data uploaded to the DCM secure server where it was post processed and published to a client Web portal as trend series and excel spread sheets.

The influent flow was measured by a Magflo meter,(Yokogawa) connected by 4 - 20 mA signal to the Con::cube controller. The data was collated in real time and average into 2 min intervals. The flow data used in conjunction with the parameter measurements from the PQMS was used for the calculation of mass loads for each parameter.
This data set is comprised of 21,000 spectral scans a total exceeding 150,00 data points in addition to spectral fingerprinting.

In addition to the PQMS a Eureka Manta 2 in-situ water quality sonde (Eureka Environmental, Tx USA) was deployed with is sensors measuring 500mm below the surface. The sensors on the sonde included Temperature (C^0), dissolved oxygen (DO), Turbidity, pH . The sonde was deployed in Pond One, in the influent stream raceway. A second recording DO probe (YSI Co. USA) was deployed in the effluent discharge flow behind the Aquarator. A third DO probe (YSI Co. USA) was deployed off the side of the pond. The three DO probe results were averaged over one week. (Figure 1)

TSS measurements were taken every two minutes on the influent to Pond One for three weeks and the effluent from Pond One for one week.

The influent TSS for treatment, in a municipal system, is predominantly comprised of faecal biological matter including bacteria, food materials, human waste, and biological by-products.
At various times lumps of fat were observed floating in Pond One which means either some traps were not serviced before they overflowed or there are grease traps as yet unknown to the contractor and therefore are not included in a regular service program. Some food preparations sources may not have adequate grease trap facilities.
Adequate primary treatment is essential to ensure that suspended solids are not present at levels that degrade the biological habitats of the receiving waters.

The prime directive for treatment within a ponding system is maintaining a rate of biological activity sufficient to ensure, as much as possible, the consumption of organic solids, followed by settling prior to discharge. Settled solids can be physically removed (desludged) by mechanical processes. Sludge removed from the ponds is put in Geo tech bags which allow water to drain thereby reducing the volume up to 80%. At the completion of this passive drying cycle the solids will be inert and able to be disbursed to landfill. (Photo 1)

You can think of a treatment system as a biological machine and like any machine runs efficiently when at a constant speed. Intermittent shock loads due to the arrival of buses to the caves and the way the toilets are used means that influent substrate is received in large amounts intermittently.

For effective treatment in a biological process the dissolved oxygen level needs to be maintained above 50% saturation in all parts of the aeration basin. Where nitrification is required the dissolved oxygen needs to be 20% saturation or higher in all parts of the basin.

The oxygen balance is a result of integration of all the processes that influence oxygen dynamics. (McBride and Chapra 2005) (Craigs et al 2004) which include ;

i) Air provided by physical transfer from the atmosphere through the surface of the pond.is also influenced by the roughness of the pond surface i.e. wind.

ii) Air provided by fine bubble diffusion from the Aquarator aeration/mixing system.

iii) Oxygen provided by algae undergoing photosynthesis in sunlight. *(Oxygen produced by photosynthesis is essentially free in that it has no energy cost and therefore is to be encouraged wherever possible*.)

The variation of atmospheric pressure contributes less than 1`% DO change and this context is not considered significant. While oxygen levels within the pond water are affected by temperature (i.e. saturation of oxygen decreases with the increase in temperature) the relationship between oxygen transfer for any source is an inverse logarithmic relationship dependant on the concentration of oxygen in the water. (Benson, and Krause,. 1980). The Aquarator runs 24 hours a day and therefore the amount of air delivered is constant over a 24 hour period. The amount of oxygen absorbed varies with respect to concentration on oxygen in the water.
By examining the diurnal oxygen profile and by using a model e.g. the approximate Delta method (McBride and Chapra 2005) you can determine the influence of each parameter in real terms – Isolating for example the Aquarator influence . A good example of using this model (DO FLO) (Wilcock et al 1998)

In this application, the purpose of aeration is to provide sufficient oxygen for nitrification of ammoniacal nitrogen. The amount of aeration required is in direct relationship to the mass load of the COD in the influent. The mass load defines the kg/hr of oxygen required to achieve compliance.

More treatment cells operated in series will produce a lower effluent concentration given the same overall retention time and operating temperature.

3.0 Results

Oxygen profile measured by YSI DO probes reveals a clear daily diurnal pattern see Figure 1. The diurnal oxygen curves in the initial days show a maximum oxygen inflection point at about 15:00 hrs with a concentration of 4.17mg/l and is relatively constant for the first three days and we infer the weather to be overcast compared to the last three days. The last three days show significant increase in peak oxygen which still occurs about 15:00hrs. The last day we would expect to be full sunshine. Because the lowest DO and Temp occurs just before sunrise we can infer the significant oxygen increase is a reflection of algal oxygen production by photosynthesis

On the sixth day we achieved DO of 10.98mg/l at 13.14 ^{0}C this is around the saturation value of DO at that temperature .

There is a strong correlation between pH and oxygen which point to the situation that algal activity is driving this oxygen result.

As the sun comes up the algae strip the CO_2 out of the water and the water goes alkaline . After peak sunlight on any given day the oxygen become less intense and gradually the CO_2 feeds back into the water by respiration (and also reaeration from the atmosphere) .

Tests indicate Pond 1 is receiving an Ammoniacal Nitrogen load at 120mg/L and discharging at .31mg/L currently achieving an ammonia reduction of 67%. improvement.

Inhibitory effects — no toxins or inhibitory compounds that would debilitate nitrifying bacteria were found.

Trend analysis of effluent Pond One (Figure 2) shows that the plant is working very effectively. The lower graph shows the influent flow with its erratic shock loading from pump outs and the method by which influent is delivered to the system. It can be seen in the COD CODf, TSS, NO_3 and pH that the pond is working effectively in providing a buffer. Further it can be seen that all required parameters are being discharged at a level significantly lower than the consent requirements. Nitrate levels are consistently below 2 mg/L, and TSS consistently below 100 mg/L .

There is a clear difference between effluent and influent reading for Pond One. (Figure 3) The inflow results show that the shock loading is continuous and the pond has a buffering capacity and treatment ability to level these out. pH on the influent with its wild variation is somewhat of a puzzle at this point and needs further investigation. In general, faeces and urine are around the neutral pH when leaving the body. Urea is produced by our kidneys and the wastewater bacteria split the carbon nitrogen bonds and forms hydroxyl ions (ammonium NH_4^+) which tends to be basic. Generally, soaps and soap scums are also strongly basic so the high pH could also be reflecting some form of laundry or other cleaning product effluent This needs further investigation before a definitive conclusion can be drawn.

TSS measurements were taken every two minutes on the influent to Pond One for three weeks and the effluent for one week (Figures 2,3,4)

Since the installation of the Aquarator system the pond treatment capacity has not been exceeded and the ammonia levels have not breached consent levels even though the shock loading is seen to be continuing. See Figure 3 Figure 4

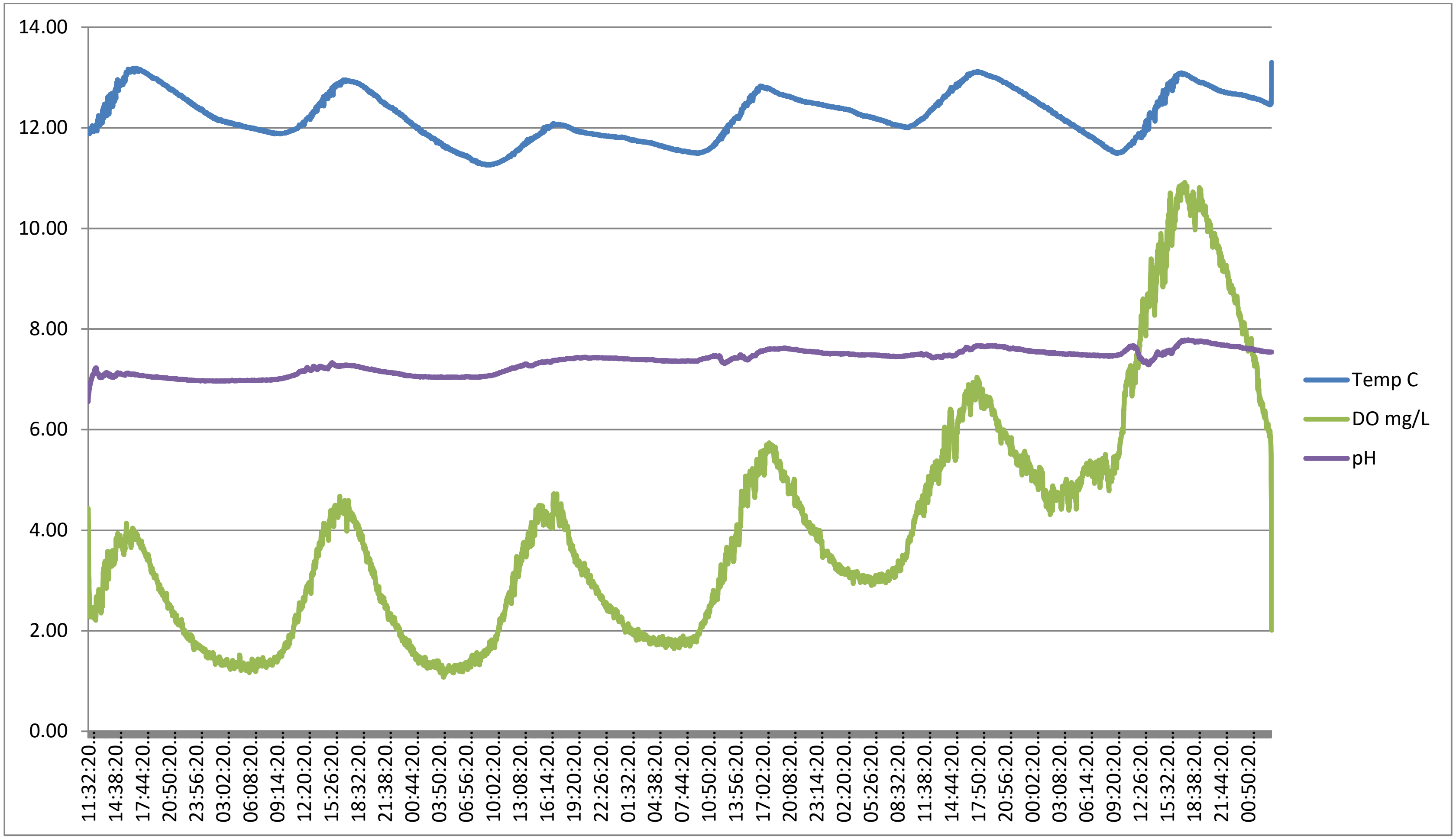

Figure 1 Dissolved Oxygen, pH and Temperature plot showing Diurnal profile Begins 11:32 0n June 15 2016

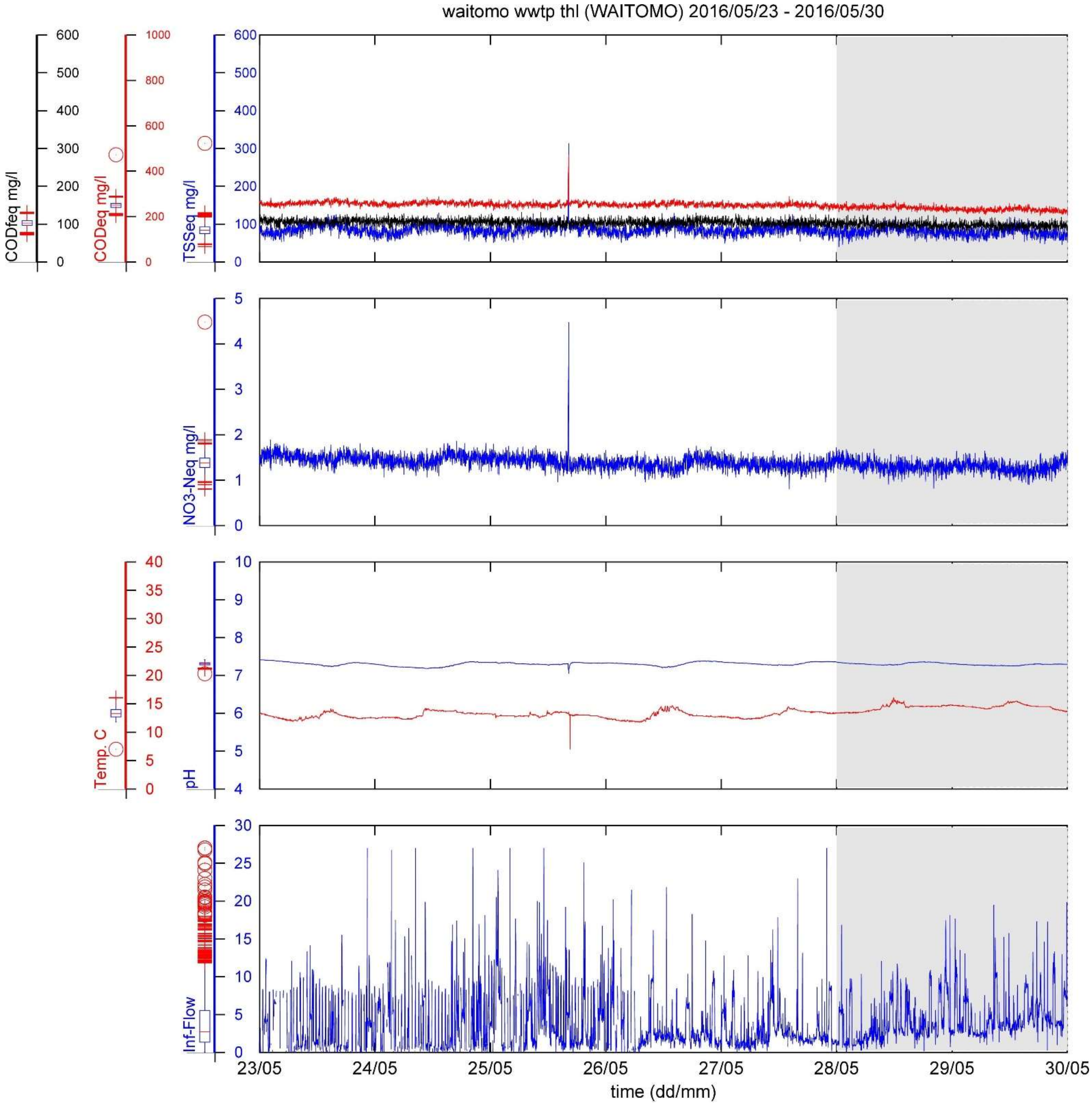

Figure 2 Effluent from Pond One _ Time series taken from the spectral Data of the DCM PQMS

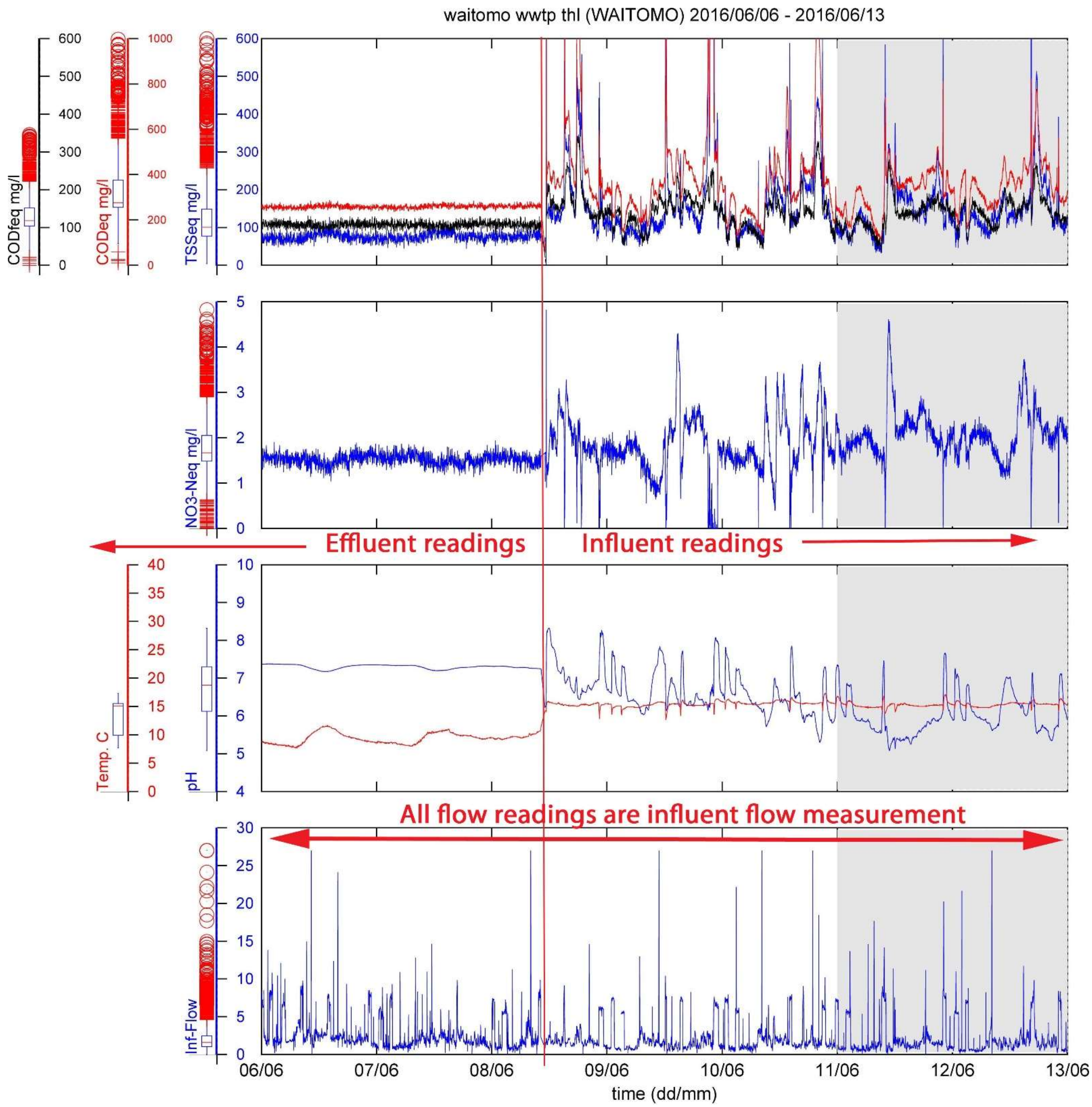

Figure 3 Effluent and influent trend series Pond One_ Time series taken from the spectral Data of the DCM PQMS

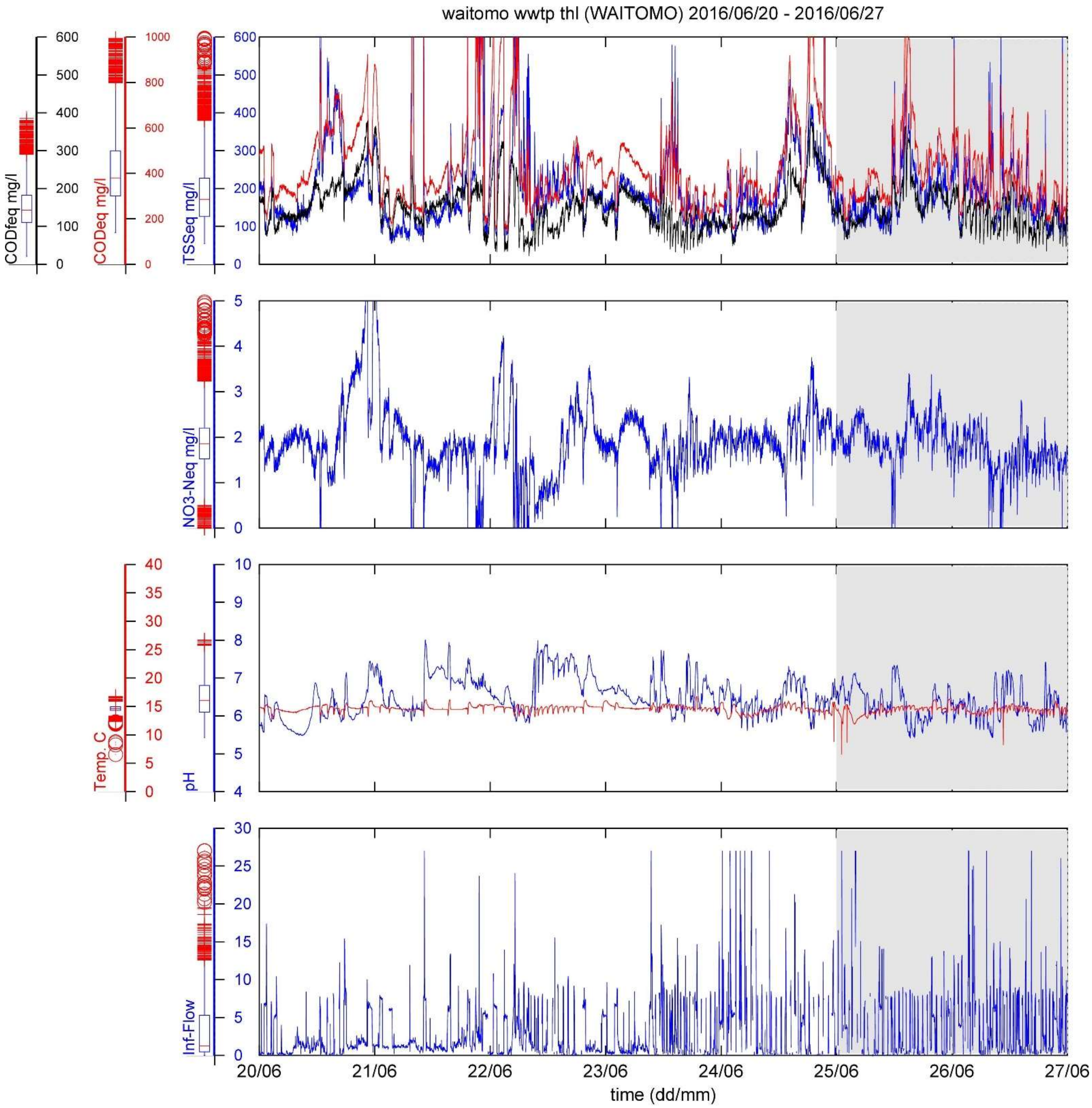

Figure 4 Influent received by Pond One _ *Time series taken from the spectral Data of the DCM PQMS*

Discussion

Algae photosynthetically produce pure oxygen (500% DO saturation). The Aquarator enhances the aerobic bacteria. The enzymatic action from the aerobic bacteria makes available the nutrients required for algal growth. This is a very useful biochemical process the oxygen production by the increased algal growth enhances overall oxygen supply. By optimising the pond system, you can utilise the algae as an oxygen generator and reduce the need to supply electrical energy. This also means you could increase influent loading during the day. As long as oxygen is available COD and BOD and bio solids are consumed

Tests indicate an influent concentration of Ammoniacal nitrogen up to 120 mg/L. Tests of our system influent and effluent indicate we have at times achieved an overall reduction from 120 mg/L down to 0.31 mg/L, giving us reduction of up to 97%% below required consent level (10 mg/l) ,

Observation of how shock loads of material arrive at the plant is shown by on line monitoring and reveals the diurnal, pumping and influent reception pattern. Regardless of how the shock loads arrive a consistent level of effluent is achieved with the Aquarator in place indicating the buffering and treatment capability of Pond One is sufficient for the load received.

Pond nitrification is pH-sensitive, and ammonia treatment rates decline significantly at pH values below 6.8. Optimal pond nitrification rates occur at pH values in the 7.5–8.0 range results tend ot indicate that Algal photosynthesis and respiration has greater effect on pH than shock loads of influent at June levels (intense shock loads of ammonia can alter pond pH in the short term)

Nitrification often slows as water temperature decreases. Nitrification generally decreases or ceases in winter. Our monitoring was completed in June traditionally the shortest daylight hours However in June traditionally high rainfall keeps the temperature high. We could reasonably expect increase saturation and activity in warmer months

Bacterial attachment to living organisms has been observed in freshwater ecosystems (Kansiime and Nalubega,1999) (Hans W.P 1975)

Bacteria may form biofilms in aquatic ecosystems on surfaces of suspended matter including algae**.** ***(A**s the diameter of the suspended solids decrease from 10 micron to1 micron the surface area goes up by the square of the diameter**)***

From an associated study of the Ratana WWTP similar significant decrease in water quality parameters were observed. Measurement of phosphorus levels showed phosphorus was also decreased by 50% in the aeration basin the Aquarator was in. We infer the phosphorus decrease was caused by the increase in biomass from the aerobic process and these microbes would fix the phosphorus in their cells and deposit in the sludge or taken out as biosolids. From this we can infer the same process occurs in Waitomo and that Aquarator has an effect on Nitrification and phosphorus removal. Rangitiki District Council and Eurofins ELS (Pers.Com.)

A comprehensive evaluation of the maintenance and energy usage of the Aquarator was done for a similar study and it was found (Pers. com. Paul Cheshire) that is was significantly cheaper to operate

The Aquarator has an increased efficiency compared to brush aerators. Aquarator is shore based making of ease of service and operation without having to go on the ponds

Conclusions

1. The Aquarator introducing compressed air and using an innovative horizontal venturi action consistently increased the dissolved oxygen levels in Waitomo WWTP pond one.
2. The amount of oxygen introduced enables the nitrification of high levels of ammoniacal nitrogen greater than 10mg/l (but sometimes exceeding 120 mg/l) to nitrate.
3. Other parameters which measured wastewater strength also showed significant decreases in concentration in Pond one with the Aquarator operational
4. The comparison of data from the previously recorded 9 years with that of this 2016 study using the Aquarator (instead of a brush aerator) showed compliance of all waste water parameters and in particular the Ammoniacal nitrogen.
5. The Aquarator – showed a significant increase in pond assimilative capacity to be able to comply with most future demands.
6. Aquarators are cheaper to run and maintain than conventional aeration systems

Waitomo WWTP – De-watering area, Stream, and surrounds

Photo 1 Aerial Image copyright to John Nagels 2017

ACKNOWLEDGEMENTS

Robert Tahi Service Manager Tourism Holding ltd, John Guy Food, Health and Environmental, Rob Dexter principle DCM Process Control Ltd.

REFERENCES

Benson B.B, and Krause, D. 1980. The isotopic concentration and isotopic fractionation of oxygen dissolved in fresh water and seawater in equilibrium and the atmosphere. Limnology and Oceanography. 29(3) 620-633pp

Craggs, R. Zwart, A., Nagels, J.W. . Davies-Colley, R.R., 2004. Modelling sunlight disinfection in a high rate pond. Ecological Engineering 22 2004. 113–122pp

Hans W. P. (1975), Microbial attachment to particles in marine and freshwater ecosystems.. Microbiology March 1975, Volume 2, Issue 1, pp 73–83

Kansiime, F. and Nalubega, M. 1999. Wastewater treatment by a natural wetland: The Nakivubo Swamp, Uganda, Process and Implications. PhD Thesis, Wageningen Agricultural University and IHE, The Netherlands.

McBride, G.B. and Chapra,. S.C. 2005Rapid calculation of oxygen in streams: Approximate delta method. J. Environ. Eng. 2005, 131, 336–342pp,

Wilcock , R.J., Nagels,J.W.,McBride,G,B., Collier, K.J., Wilson,T., Huser,B. 1998 Characterisation of lowland streams using a single-station diurnal curve analysis model (DO FLO) with continuous monitoring data for dissolved oxygen and temperature. New Zealand Journal of Marine and Fresh Water Research 32.67-79pp