USE YOUR C TO REDUCE YOUR N AND P – PORT MACQUARIE WASTEWATER TREATMENT PLANT

Richard Brice – AWT Australia Pty Ltd
Clayton Miechel – Port Macquarie-Hastings Council

ABSTRACT

Port Macquarie is a large town located on the Mid – North coast of New South Wales (NSW) approximately 390km north of Sydney and 570km south of Brisbane[i]. The population for Hastings Valley is recorded in 2006 to be approximately 39, 000.

The purpose of this study is to exhibit the use of on line instrumentation to allow the Port Macquarie – Hastings Council to optimize the Port Macquarie Wastewater Treatment Plant. This optimisation was particular to Enhanced Biological Phosphorous Removal (EPBR) which until this time has not been achieved at the plant.

Results indicate that EBPR is possible; however this is dependent on effective denitrification. This has had the benefit of reducing power consumption and clearly will reduce the requirement for post secondary treatment dosing of Alum.

This paper discusses the mechanisms by which EBPR was exhibited and utilised at Port Macquarie WWTP and presents how effective on line instrumentation is essential for both evaluating potential for EBPR and control of the plant operation.

KEYWORDS:
EAT Basins, Nitrogen, Phosphorous, FRP, s::can, Dissolved Oxygen, ORP.

Introduction

Port Macquarie is a large town located on the Mid – North coast of New South Wales (NSW) approximately 390km north of Sydney and 570km south of Brisbane[ii]. The population for Hastings Valley is recorded in 2006 to be approximately 39,000.

Port Macquarie-Hastings District owns and operates the Port Macquarie Wastewater Treatment Plant (WWTP). The Port Macquarie Wastewater Treatment Plant is configured as three parallel IDEA (EAT) basins and was originally designed to biologically remove both Nitrogen and Phosphorous.

The process has however always struggled to remove both Nitrogen and Phosphorous simultaneously and Alum has been dosed to the final effluent discharge point to ensure that the nutrient standards required by the NSW EPA will be met. Long term usage of

Alum has resulted in significant amounts of Alum sludge being deposited within the effluent lagoons. Due to this, Port Macquarie-Hastings Council has removed the Alum sludge from the lagoons at significant cost.

This paper focuses on the utilization of the s::can and other instrumentation to provide both feed forward and feed back control of the reactor basin for enhanced N and P removal. It outlines the functionality alterations that have provided the ability to substantially reduce the final effluent Total Nitrogen and Phosphorous concentrations, as well as reduce power and other consumables. This control involves the use of the s::can, Zullig DO and ORP probes and improved functionality to provide for EBPR in a similar fashion to that described by Serralta et al (2004)[iii].

Of the three basins EAT 1 was utilised as a pilot system. It is recognized that the return Phosphorous concentrations from EAT 2 and EAT 3 will increase the overall return load to the plant given the alterations were not made to these basins. Clearly this is a significant load within the return stream; however the pilot plant was conducted to evaluate the power savings, the potential improvements with the effluent quality and in particular the potential for biological Phosphorous removal.

Figure 1 below presents an overview of the Port Macquarie WWTP including the positions of the new instrumentation installed as part of this project.

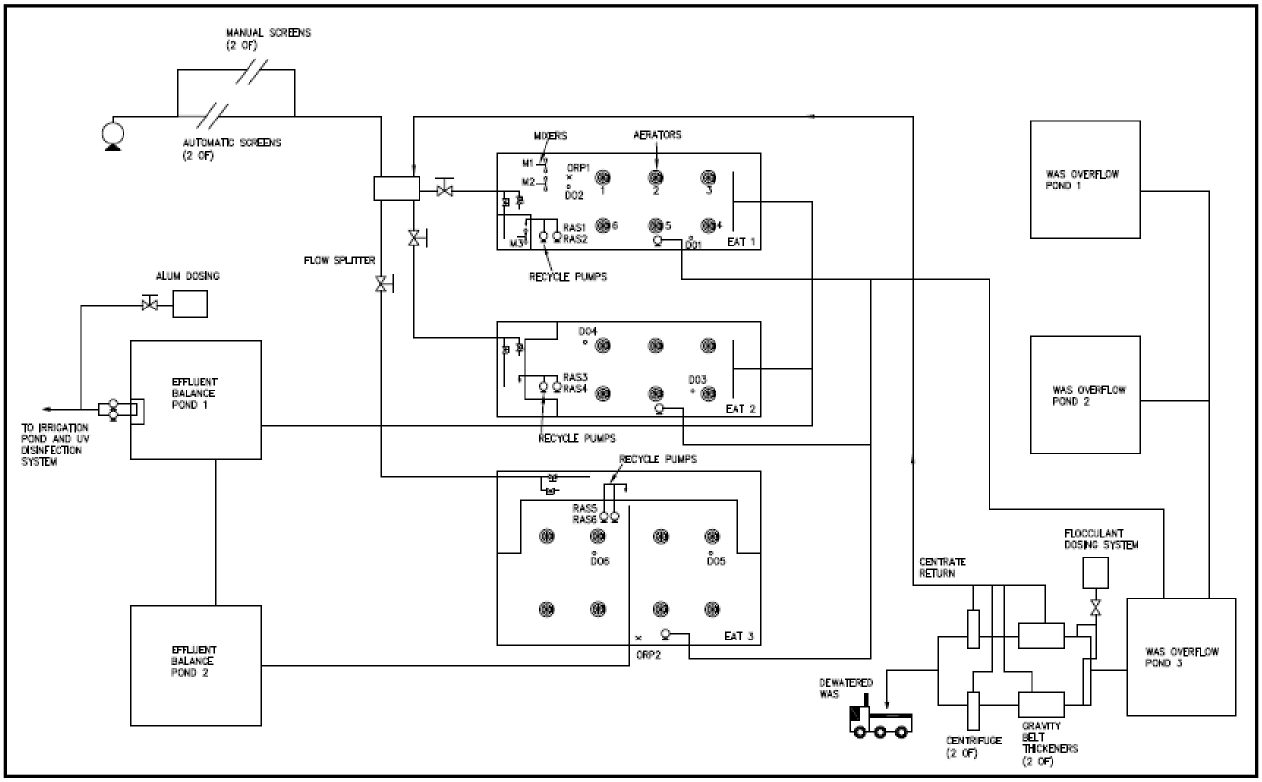

Figure 1: Port Macquarie WWTP General Arrangement

Materials

All samples were collected and analysed on site at the Port Macquarie Wastewater Treatment Plant. Samples were collected from the inlet chamber post screening (also the position of the s::can spectrolyser); from within EAT 1 at various points and from the final EAT 1 effluent.

The s::can was calibrated against inlet grab samples; with samples recorded and inserted into the s::can as per the calibration methodology provided by the system suppliers (DCM Process Control). The s::can has been set to take 1 sample per minute; however this can be altered depending on the situation requirements.

Sample Collection: 24 hourly composite samples are taken on a weekly basis on the influent and effluent points for compliance purposes for the NSW EPA discharge license. Grab samples are taken from the influent for calibration of the s::can, from within the reactor for nutrient profiling and from the individual effluent decants to compare diurnal data. Further to this, grab samples were also taken for laboratory based rate analysis of Phosphorous release and uptake concentrations.

On line Instruments: two Zullig Dissolved Oxygen (DO) probes (model S-14S) were installed within EAT 1 and a Zullig Oxidation Reduction Potential (ORP – pHBL - 25) probe installed alongside the DO probe. The location of these is presented in Figure 1 above.

An s::can UV/Vis spectro::lyser was used to evaluate the diurnal patterns within the influent stream, particularly for COD (BOD_5 was the main plant parameter for operation prior to this investigation, and BOD_5 values were also reported). Clearly the amount of degradable carbon entering the plant will define the amount of Denitrification and Phosphorous release attainable within the process. The on line instrumentation is set up to be evaluated in real time and provides detailed data which is extremely useful for not only the operation of the plant but also for design purposes. The plant operation is able to be controlled by the s::can and a combination of DO and ORP probe outputs.

Equipment: Two new 7.4kW Flygt mixers were installed at the front end of EAT 1.

During these investigations AWT have undertaken actual Phosphorous release rate and uptake rate testing to ensure Phosphorous organisms (PAOs) are present (similar to that method developed by Kang et al (1991)[iv]. Tests were undertaken on site using the HACH spectrophotometer (DR2400 and methods 8114, 10031, 8000 and 10020).

The batch tests were undertaken on site at Port Macquarie WWTP. These tests were completed as per the method presented with the STOWA manual by Jansen et al[v].

Targets – Effluent Quality

Table 1 presents the discharge license limits for the Port Macquarie Wastewater Treatment Plant. The key parameters are the Total Nitrogen and Phosphorous limits.

Table 1: Port Macquarie Discharge License Limits

Parameter	Limit 50%ile	95%ile	Maximum	Units
BOD_5		10	20	mg/L
TSS	10	15	30	mg/L
Ammonia	2	5	15	mg/L
Total N	10	20		mg/L
Total P	0.7	1		mg/L
Oil and Grease		2	10	mg/L
Faecal Coliforms		200		cfu's/100mL

The Port Macquarie WWTP had been designed to biologically remove Nitrogen and Phosphorous to the levels presented above. Total Nitrogen levels have not traditionally been difficult to meet, however due to the plant being unable to meet Total Phosphorous limits an Alum dosing system was subsequently installed which adds alum to the final discharge stream from the treatment plant.

Plant Alterations

The pilot plant trial (EAT 1) commenced in early June 2006; with operation of the plant being undertaken by the plant operators; with remote assistance utilizing the on line instrumentation from AWT staff.

A mixer was installed in the anoxic zone and the anaerobic zone in an effort to keep these zones fully mixed.

The aerobic zone consists of a tank containing six surface aerators with a decant system prior to discharge. A mixer is also installed in this zone.

The following alterations have been completed within EAT 1 in an effort to allow EBPR removal to take place:

- The mixer in the anoxic zone was removed.
- Two new mixers were installed in the main reactor basin.
- An ORP and a DO probe were installed at the "front end" of the aerobic/anoxic zone.
- The s::can was installed in the influent line to measure incoming loads for control and design purposes.
- New control functionality to utilise the above for EBPR was written.

It should be noted that a DO probe was already installed within the reactor which was used for control. This was not moved or altered in any way.

The trial was halted over the summer of 2006/2007 due to problems with accessing the site SCADA system and then recommenced in April 2007. EAT 1 has been operating uninterrupted using the new functionality since this time.

Subsequent to these trials the other two basins (EAT 2 and EAT 3) are in the process of been altered as per the above.

Methods and Theory

EBPR Theory

EBPR is broadly dependent on the following parameters:

- Readily degradable organic carbon and phosphorous in the influent.
- Sufficient anaerobic zone volume (from hydraulic and solids retention time basis).
- Sufficient cations (e.g. Magnesium and Potassium) to facilitate the release and uptake of Phosphorous.
- Reduction (where possible) of non – PAOs in the anaerobic zone.

The degradable organic carbon is essential for Phosphorous release in the anaerobic zone. Research from Baetens[vi] states that it is usually assumed that this degradable carbon needs to be in the form of volatile fatty acids (VFAs) mainly in the form of acetate, propionate or butyrate, or in a form that can be easily hydrolysed or fermented to VFA within the process.

In the process, biomass passes through an oxygen and nitrate free zone, an anaerobic zone, prior to entering an anoxic and/or aerobic zone where oxygen as an electron acceptor is present.

When the wastewater enters the anaerobic zone poly-phosphate accumulating bacteria (PAOs) accumulate carbon sources (degradable carbon is readily accumulated) as an internal polymer within the cell, most commonly as polyhydroxybutyrate (PHB). The energy used in this reaction is obtained from breakdown and hydrolysis reactions of the poly – Phosphate (poly – P). The poly – P is broken down to orthophosphate in the anaerobic zone and as such the total P concentration in the anaerobic zone increases.

When the PAOs move into an anoxic or aerobic zone, the polymer (most commonly PHB) is consumed, generating energy for growth and the orthophosphate is taken from the liquid. This is then bound within the cell and removed via the sludge wasting process (it must be noted that the wasted sludge must be retained in an aerobic form or the secondary P release process will occur and orthophosphate will be returned within the return liquors). Under these conditions the orthophosphate concentration decreases.

In this uptake process the biomass is then capable of storing up to 4 - 12% of their dry weight. This is a net gain in Phosphorous stored within the biomass cell, up from typical values of approximately 1.5 - 2%. As such, wastage of solids results in approximately 2.5 to 4 times more Phosphorous being removed from the system than in conventional systems.

Initially it was thought that this just occurred in the aerobic zone; however there are mechanisms for anoxic P – removal which can have some advantages over simple anaerobic/aerobic system; with relation to sludge production, oxygen requirements and sludge settle ability.

Methods

An s::can (on line UV spectrophotometer) was installed on the influent stream to measure influent COD concentrations in real time to evaluate the potential for Enhanced Biological Phosphorous Removal (EPBR). An initial process simulation model was constructed (using the BioWin process simulation modeling package as produced/developed by EnviroSim Associates Ltd) and a simple mass balance undertaken to review this potential. From this work it was discovered that there was distinct potential to greatly optimize the plant with very minor physical alterations particularly in terms of capital outlay. This hypothesis is as per Olssan et al (2008) who suggest that effective control can increase the capacity of BNR plants by 10 – 30%[vii].

The EAT basins are essentially a Sequencing Batch Reactor (SBR) which operate on a fill and draw activated sludge mechanism. In fact the USEPA discuss this in their Wastewater Fact Sheet for SBRs calling the Intermittent Cycle Extended Aeration System a “modified version” of the SBR with the key difference being continuous inflow[viii]. Whilst traditionally being constructed for Nitrogen removal there is also potential for EBPR. Once the nitrate – nitrogen is utilised by micro organisms, Sulphate becomes the next electron acceptor and anaerobic conditions prevail[viii]. This is more traditional EBPR thought for Phosphate Accumulating Organisms (PAOs) (where a wastewater treatment biomass removes Phosphorous beyond its anabolic requirements by accumulating intracellular polyphosphates (polyP) reserves); with static fill conditions favouring storage mechanisms during start up[viii]. This reaction that was first documented in the late 1950s follows the pathway as follows[ix]:

Release mechanism:

- PAOs + stored Poly P + Mg^{+2} + K^{+} + glycogen + VFA→ PAOs + stored biopolymers + Mg^{+2} + K^{+} + CO_2 + H_2O + PO_4^{-3}

Storage mechanism:

- PAOs + stored biopolymers + Mg^{+2} + K^{+} + O_2 (or NO_3) + PO_4^{-3} → PAOs + stored Poly P + Mg^{+2} + K^{+} + CO_2 + H_2O + glycogen

Some Phosphorous is also up taken as part of the normal growth cycle during wastewater treatment and this contributes to approximately 1.5 – 2% on a dry weight basis[x].

The internal recycle to the "Anaerobic Zone" of the reactor is from the front end of the main react zone of the basins. This zone is deemed to be fully mixed, and as such if the return nitrate concentration is as per the final effluent as described by McGrath et al (2005) who state that 6mg/L is the upper limit for step feed type systems for successful EBPR (for in particular one full scale operation[xi]). This hypothesis was also supported by the site testing undertaken. Clearly then the potential for EBPR (and hence uptake) is limited by the Nitrite and Nitrate concentration within the basin. Previously DO concentrations were also being returned due to the effect of the aerator closest to the recycle pump. Further optimisation may lead to this aerator being permanently switched off. As such, the focus of the exercise was to reduce the return DO and the effluent Nitrite and Nitrate concentration as much as possible to allow for EBPR.

Further to this Dassanayake and Irvine (2008)[xii] discuss over aeration as providing a risk for uptake of Phosphorous within the aeration phase. As such there is a further benefit of reducing the aeration time to that described for Nitrate/Nitrite removal above.

Results and Discussion

The s::can measured influent COD and ammonia concentrations. Other constituents were gathered from historical plant influent sampling data. This data was utilised to assess the viability of EBPR and included in a base BioWin simulation model.

Batch tests were undertaken and Phosphorous concentrations were recorded to ensure release mechanisms were functioning. These tests measured both the Nitrate and Ortho P concentrations to assess the effect of Nitrate on P release/uptake. Figure 2 presents the results from one of the release tests undertaken comparing nitrate and phosphorous concentrations.

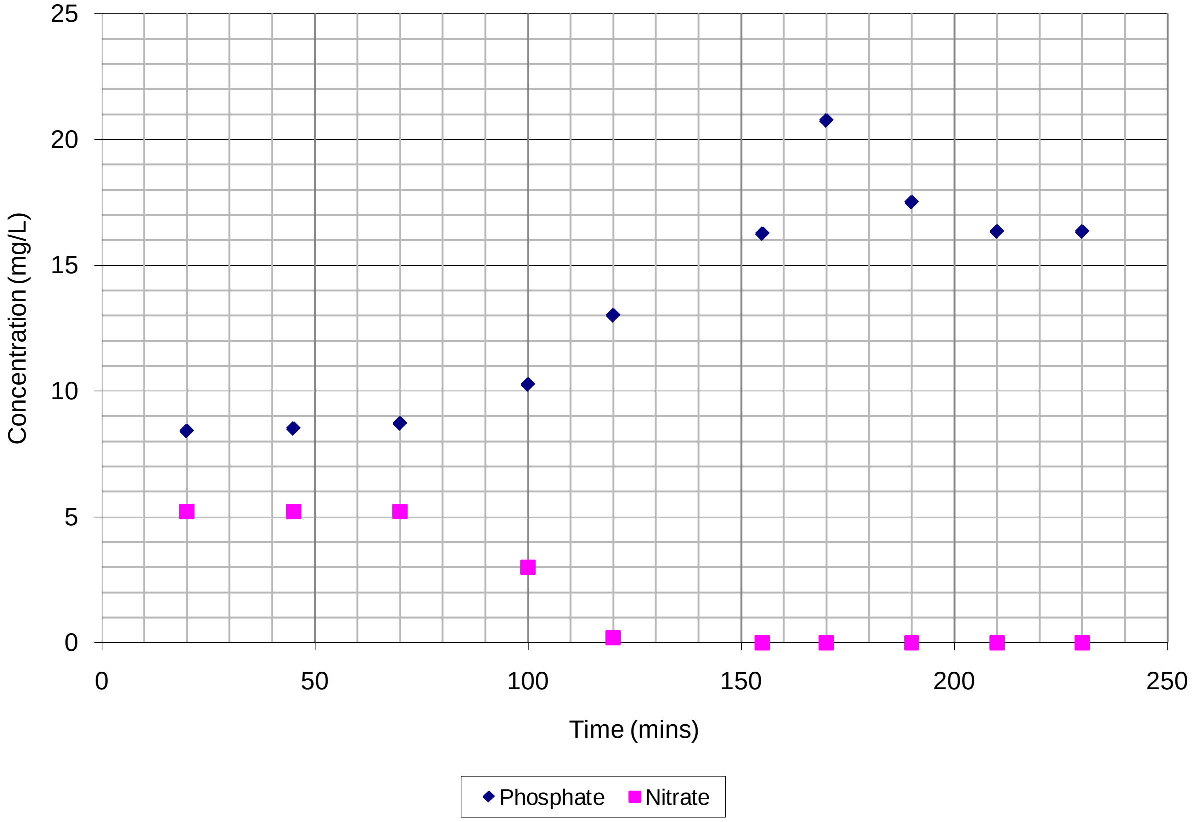

Figure 2: Phosphorous release rate tests

From both the release and uptake tests and the pilot plant trials it was quickly seen that reducing the effluent nitrate (and nitrite) concentration to a minimum allowed significantly increased Phosphorous release. As presented above rapid Phosphorous release occurs upon depletion of the nitrate concentrations within the reactor. It was however, unclear as to what conditions occurred at the end of this test; with a drop in effluent P concentrations with no alteration to the test conditions. It should be noted that Phosphorous release was witnessed in all tests.

Traditionally the discharge nitrate quality was in the order of 6 – 8mgNO$_x$/L. This had been apparent through all of the basins within the treatment plant. Basic theory of oxygen uptake will present the hypothesis that oxygen from Nitrogen will be utilised prior to the oxygen (and energy transfer) from Phosphorous. This in some way explains the situation exhibited within the onsite Phosphorous release tests with Anoxic Phosphorous release being witnessed. Further testing and research is desirable however the scope of the study did not allow time to undertake further testing to further explain some of the anomalies witnessed during the tests such as presented above.

Since the upgrade to EAT 1 with the inclusion of improved dissolved oxygen (DO) control, ORP measurement, s::can influent measurement and the installation of two new mixers within the main reactor basin, the surface aerator operation has altered to the following (influent load dependant):

- Currently an initial 30 minute aeration phase (six surface aerators);
- 60 minutes on DO control generally requiring only two of the six surface aerators.

Prior to this alteration all six surface aerators operated for the entire 90 minute “react” phase.

The initial aeration period is to allow the tank to be fully mixed during sludge wasting. This will be altered to allow all surface aerators to operate at the end of the aeration period rather than at the start. This is for two reasons, common theory for biological Phosphorous removal suggests that secondary release may occur if the process once again becomes anaerobic (i.e. during settle and decant) and from practical evaluation of the ORP profile during the cycle which backs up this theory (combined with actual sampling data during the cycle). This becomes clear when reviewing the ORP data from the on line data output as presented in Figure 3. The corresponding values from the DO probe are presented in Figure 4 as well. Level information is also recorded in real time. This data is available via a secure web site so AWT design staff (and Port Macquarie – Hastings Council staff) could review on line operation in real time and accurately and remotely assist operations staff. In fact this presented an issue of decanter failure which also allows alarm conditions to be developed for plant operation.

By superimposing the cycle over the ORP values it is apparent that the ORP values drop significantly during the decant phase with only sufficient Nitrate and dissolved oxygen to sustain or suppress the significant final drop in ORP values until towards the end of the settle phase. This is due to the end of the current phase having a low DO and nitrate concentration due to the current operation. This was not completed during the initial set up due to the age of the MCC etc not allowing this alteration to be made. This will however be altered on EAT 1 (as well as EAT 2 and EAT 3) during the upgrade and alterations to EAT 2 and 3.

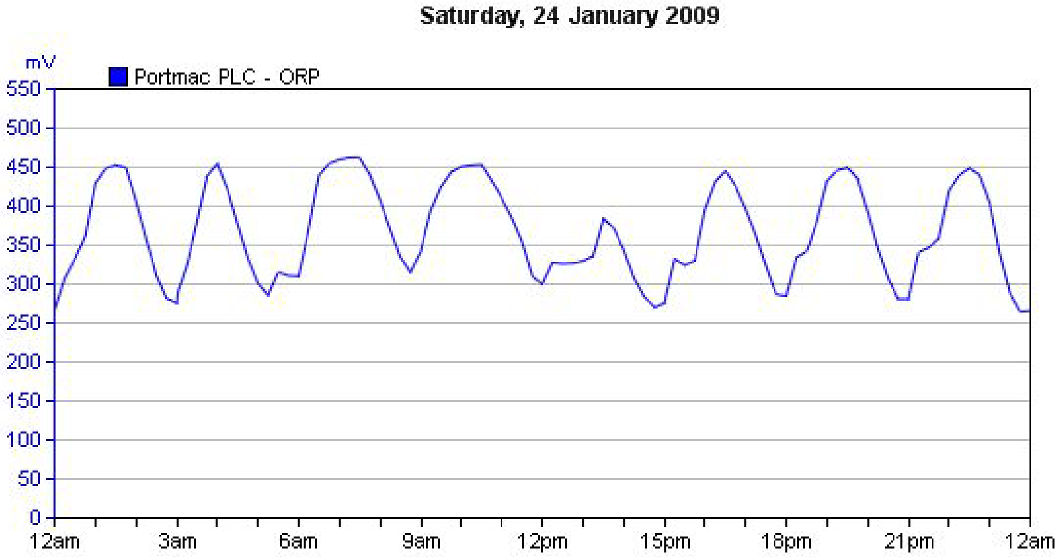

Figure 3: Real time output from ORP probe

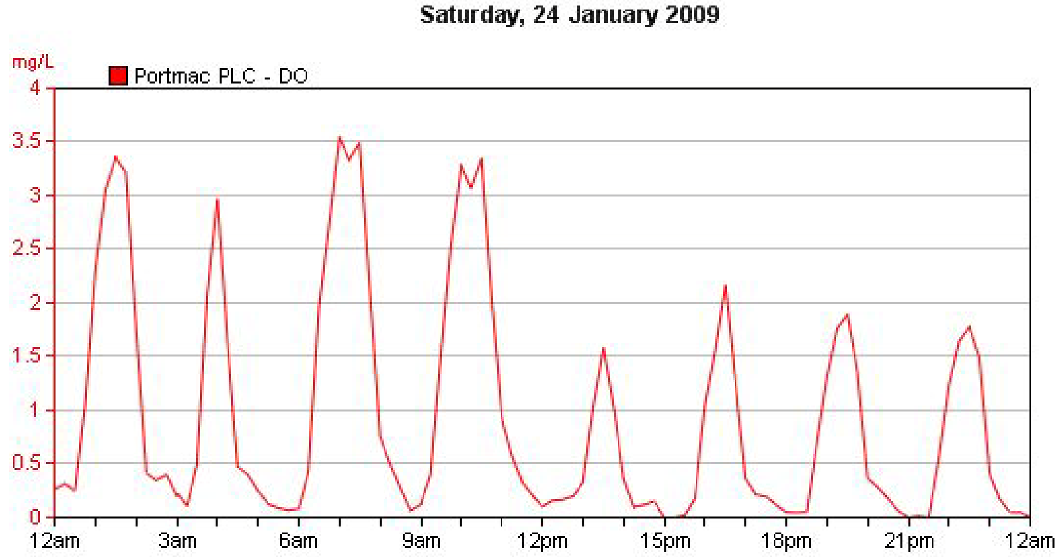

Figure 4: Real time output from DO probe

In general, loads to the plant are such that two surface aerators are sufficient to maintain the oxygen transfer required for complete nitrification and as such the other four surface aerators remain off during a large portion of the cycle. It should be noted that the DO probe presented in Figure 4 is situated alongside the two aerators that are permanently operated during the “react” phase.

Since the alterations to EAT 1 the following has been observed:

- Effluent Ammonia concentrations have remained low.
- Effluent Nitrate concentrations have reduced from an average of approximately 13mg/L to an average of 2.5mg/L.
- Effluent Phosphorous concentrations have reduced from an average of approximately 7mg/L to an average of approximately 4mg/L.

Table 1below presents the actual plant results before and after the alterations to EAT 1.

Table 1: Effluent Quality Pre and Post Alterations

Parameter	Pre Alterations		Post Alterations		Units
	Ave	95%ile	Ave	95%ile	
NH_3-N	0.8	1.1	0.4	0.7	mg/L
NO_3-N	13.4	18.9	2.6	5.8	mg/L
TP	7.2	8.6	4.3	5.6	mg/L

Weekly sampled data is also presented in Figure 1 below. There is an area of no data for effluent nitrate as this data was not available for this period. Given the reactor conditions and the on line monitoring it is not expected that this data will be different to the data prior to or after the missing data set.

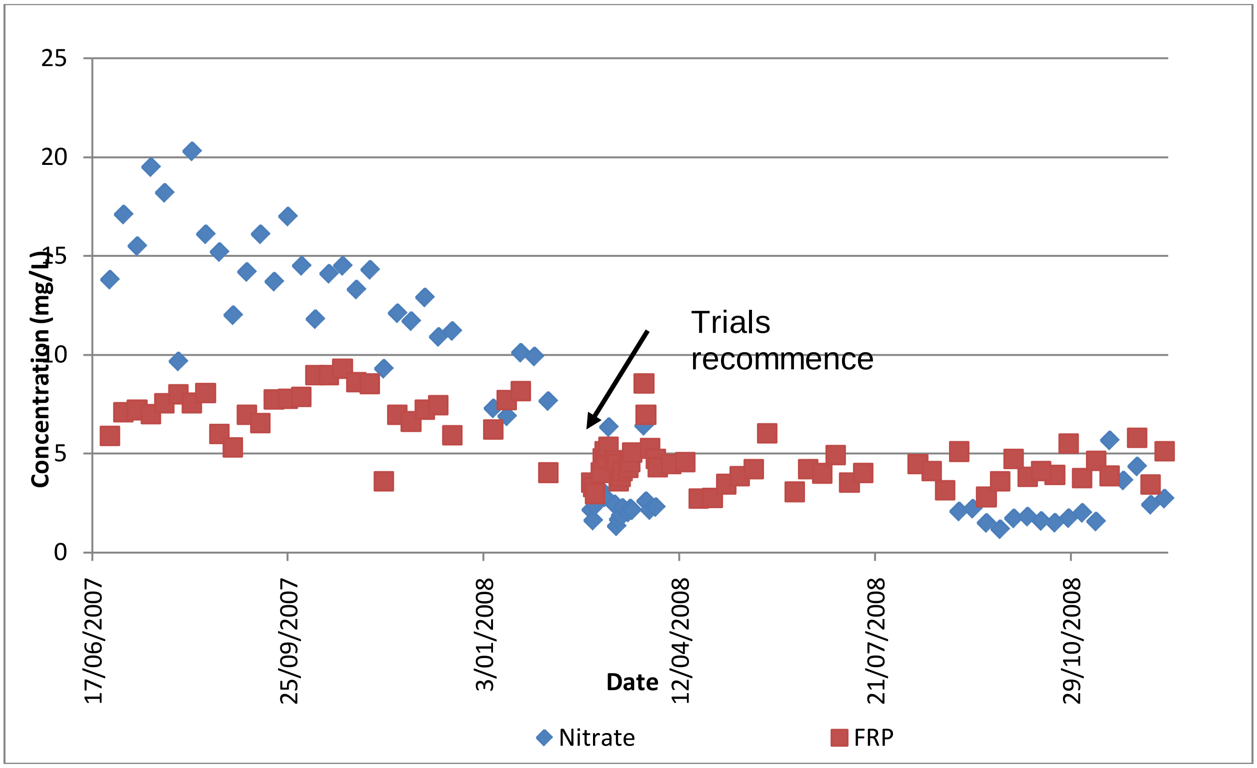

Figure 5: EAT 1 Effluent data

As presented above there is an immediate response to the alterations in the functionality and control of the plant both in terms of effluent Nitrate and Phosphorous concentrations.

A simple mass balance identified the return Phosphorous load to EAT 1 from the return streams to the plant. This equates to an extra (approximately) 1.5 – 2mg/L of Phosphorous (in terms of the effluent from EAT 1) which would otherwise not be present in the return streams.

As such Port Macquarie - Hastings District Council has realized a distinct improvement in effluent quality combined with a significant reduction in power usage. Port Macquarie - Hastings District Council are in the process of altering the remaining two basins EAT 2 and EAT 3 to operate with the new functionality.

From the above investigations and associated process enhancements it is estimated that Port Macquarie - Hastings Council will be able to realize approximately $110,000 per annum in power cost savings and the associated reduced Alum usage once all reactors have had functional alterations completed.

Further to this, significant reduction in effluent Nitrate and hence Total Nitrogen concentrations as well as effluent Total Phosphorous concentrations have been realized. This also does not allow for return Phosphorous streams from the existing reactors (EAT 2 and EAT 3) where these changes have not been implemented. As such without any further alterations or optimisation it is likely the EAT effluent will be in the order of 2mg/L once all alterations have been made. Further alterations will be made on a cost benefit basis.

Conclusions

The ultimate goal of the project is to fine tune the process in such a way as to allow forward feed control utilizing the s::can with only the DO probe and ORP probe being used as back up control. This control also allows the cycle to be controlled on a load/DO/ORP basis.

The combination of site investigations, process mass balances and accurate altered functionality has allowed for improved effluent quality, both in terms of Nitrogen and Phosphorous and has had the added benefit of reducing power and consumables.

Further improvements are being undertaken and due to instrumentation being on line, real time remote assessment and assistance can be provided.

As discussed above, the return streams from the other basins affect the effluent Phosphorous concentration. It is envisaged that this will improve with adoption of the control system over the entire plant along with altering the sludge wasting aeration procedure.

It is common for plants to be operated based on initial operations manuals written during process design. This design; particularly for older plants can also be undertaken on a BOD basis or a COD basis with significant safety factors due to the level of detail available for influent parameters during design. These manuals often lead to operation of plants based on MLSS concentrations and pre set DO concentrations. Accurate characterisation and development of simple functionality using on line instrumentation is a proven mechanism of optimizing existing assets which defers large capital expenditure and allows for improvements for effluent quality and reduction in consumables. This is important as consumable costs are often increasing and with particular regard to power; greenhouse gas emissions are of increased concern.

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[i] Downloaded 16/02/09," http://en.wikipedia.org/wiki/Port_Macquarie,_New_South_Wales",Wikipedia

[ii] Downloaded 16/02/09," http://en.wikipedia.org/wiki/Port_Macquarie,_New_South_Wales",Wikipedia

[iii] Serralta et al, 2004, "Monitoring pH and electrical conductivity in an EBPR sequencing batch reactor", Water Science and Technology, Vol 50, IWA Publishing.

[iv] Kang, S. J., T. J. Astfalk, C. J. Englert, and R. R. Deline. 1991. A new procedure for screening feasibility of biological phosphorus removal for a wastewater. *Water Science and Technology* 23:595-602.

[v] Jansen et al, 2002, "Biological Phosphorous Removal: Manual for Design and Operation" Water and Wastewater Practitioner Series, STOWA Report.

[vi] Baetens, D, 2000, "Enhanced Biological Phosphorous Removal: Modelling and Experimental Design", Universiteit Gent.

[vii] Henze et al, 2008, "Biological Wastewater Treatment – Principles, Modelling and Design", IWA Publishing, Cambridge University Press.

[viii] USEPA, 1999, "Wastewater Technology Fact Sheet: Sequencing Batch Reactors", Office of Water, Washington D.C.

[ix] WEF, 2008, "Municipal Nutrient Removal Technologies Reference Document, Volume 1 – Technical Report, WEF.

[x] WEF (Water Environment Federation), 2004, and ASCE (American Society of Chemical Engineers) 1998, "Design of Municipal Wastewater Treatment Plants, WEF Manual of Practice 28", WEFPress, Alexandria, VA, USA.

[xi] McGrath, M., G. Shero, and J. Welton. 2005a. Fermentation for Improving Nutrient Removal at a Virginia Wastewater Treatment Facility. In Proceedings of the Water Environment Federation's 78th Annual Technical and Educational Conference, Washington, DC, October 29–November 2, 2005.

[xii] Dassanayake, C and Irvine, R, 2001, "An enhanced biological phosphorous removal (EBPR) control strategy for sequencing batch reactors (SBRs)" Water Science and Technology, IWA Publishing.