RESEARCH UNDERTAKEN TO IMPROVE SUSTAINABILITY AND REDUCE COSTS OF BNR PLANTS

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ABSTRACT

In designing the 75,000 Person Equivalent (PE) Biological Nutrient Removal (BNR) Plant for Queanbeyan Palerang Regional Council in NSW Australia we challenged some of the accepted design assumptions. In doing this we undertook four targeted research projects to remove risks, lower cost, and improve treatment performance. All projects have been designed into the new plant and the research projects are summarised below.

Enhanced Chemical Phosphorus Removal. In exploring the operation of the current Queanbeyan plant we discovered unusually efficient performance with the current chemical phosphorus removal process. We explored this further and undertook extensive jar testing and discovered a new more efficient chemical phosphorous removal approach. By co dosing calcium with ferric chloride a considerable reduction in the chemical use by up to 40% can be achieved. An additional advantage is the reduction in sludge production by up to 10% when compared to ferric chloride only dosing. Adopting this approach will save $270,000 per year (for 75,000 PE) compared to single chemical phosphorus removal.

Low Energy Hydraulic Mixing. A pilot plant was run to investigate how to use the energy in the inflowing stream to remove the need for mechanical mixing in unaerated zones. The pilot plant identified how to configure under and overflow baffles to mix sludge. We found full mixing was possible with only a low additional head loss through the reactor. This approach reduced the mixing power cost by 95% ($0.34/PE per year reduction in operating cost) compared to conventional mechanical mixing. It also eliminated the need for ongoing maintenance costs for mechanical mixers.

Enhanced Storm Treatment. Improved gravity clarification using a solids contact approach was investigated. This research identified partial bypassing of the activated sludge reactor in wet weather and recombining it with activated sludge in a gravity clarifier almost doubles the clarifier capacity without impacting UV disinfection performance. This saved significant capital cost (~ $10M) on this project and enabled high volumes of storm flow to be disinfected with smaller clarifiers.

Slow the Oxidation Ditch Down. Normal practice is to run oxidation ditches at flow velocities of at least 0.3 m/s to ensure mixing. However, slowing this velocity has other benefits such as reduced energy use, lower ammonia in cold climates,

and higher biological phosphorus removal. The nutrient removal benefits come from being able to achieve a higher dissolved oxygen at lower velocities. We investigated how low the velocity could be lowered in an operating plant in Townsville and still maintain mixing. We found the velocity could be lower by up to 50% and maintain mixing for low solids concentrations which are challenging to mix. This significantly challenged well entrenched accepted design standards for oxidation ditch mixing.

KEYWORDS

BNR, Mixing, chemical, phosphorus, removal, energy, disinfection, UV, cost

PRESENTER PROFILE

Liam Tamplin - Liam is a process engineer with 4 years' experience since graduation in both hands on operational and technical engineering roles. He has experience across a range of wastewater projects from problem definition and options development, through concept and detailed design.

Craig White – Is a process engineer with 28 years' experience in wastewater treatment investigation, design, operations, and tertiary education. He has led, designed, and commissioned many BNR plants in a range of cold and tropical conditions. Craig is an Adjunct Associate Professor at the University of Newcastle.

OVERVIEW

The Queanbeyan Sewage Treatment Plant (QSTP) was initially constructed in the 1930's and is nearing the end of its assets life and reaching capacity. The QSTP upgrade will replace the existing plant with a modern treatment facility that will improve capacity and quality.

Queanbeyan Palerang Regional Council (QRPC) engaged Beca Hunter H2O to design a new 75,000 EP plant at the same site as the existing QSTP. After an extensive review of options, a 4 stage Bardenpho oxidation ditch reactor followed by tertiary filtration and UV disinfection was selected for design.

In the design process we challenged some long-accepted industry design assumptions and used targeted research to ensure a more sustainable outcome by better understanding risks, minimizing costs and improving effluent quality performance. The assumptions challenged included:

1. Enhanced phosphorus removal using a combined lime and ferric dose to reduce chemical use and improve phosphorus removal.
2. Enhanced storm treatment using solids contact bypass system as opposed to a full plant bypass of storm flows.
3. Low energy hydraulic mixing as opposed to conventional mechanical mixing techniques.
4. Slowing the oxidation ditch flow velocities below the typically used standard of 0.3 m/s to improve quality and minimise energy use.

Practical research was undertaken on a range of existing treatment plants. The aim being to remove unnecessary conservatism or knowledge gaps to improve the sustainability of BNR designs. Some aspects of the research are also directly applicable to existing operating plants and can be used to further optimise them.

This paper details key findings which will improve the sustainability aspects of current and future BNR designs in New Zealand and internationally.

1 ENHANCED CHEMICAL PHOSPHORUS REMOVAL

1.1 INTRODUCTION

Chemical phosphorus removal typically involves dosing either an iron salt (typically ferric or ferrous chloride) or aluminium salt (typically aluminium sulphate known as alum) into the activated sludge process. A chemical precipitate is formed and is enmeshed in the biological floc and settles with it resulting in phosphorus removal. To achieve low phosphorus residuals less than 0.1 mg/L high molar doses above 7 mole metal per mole of phosphorus are required along with filtration. This results in high operating cost, increases biosolids production and adds to effluent salinity.

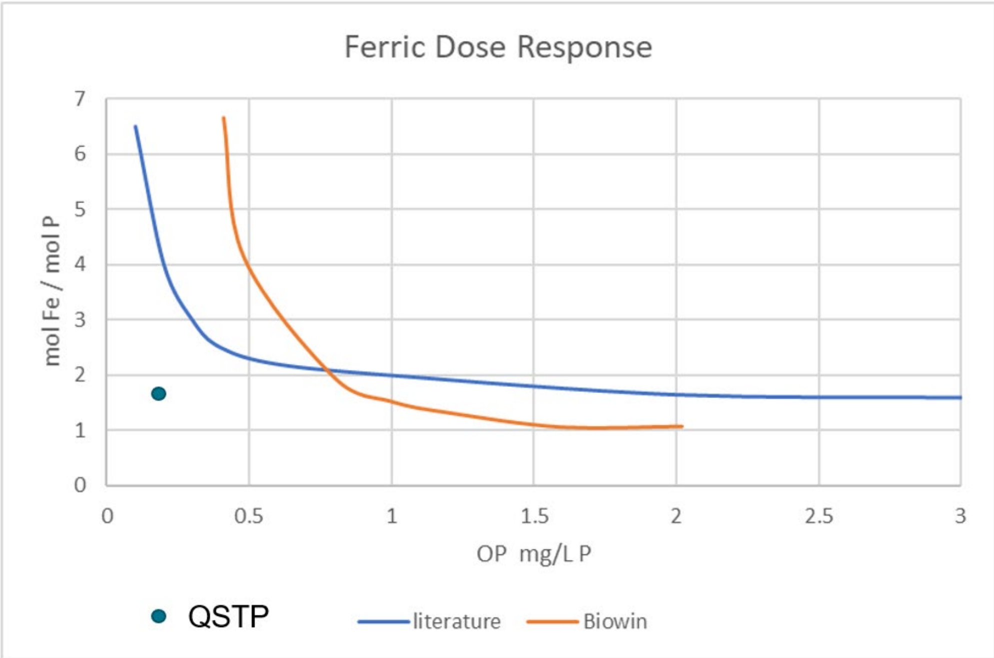
The upgraded QSTP effluent quality licence limit will be low at 0.1 mg/L total phosphorus. We discovered the current plant was using considerably less ferric chloride then typically required and predicted by modelling software such as the Biowin^{TM} simulator. The only difference at this plant was lime was dosed along with ferric chloride. This led to further investigation and research to better understand the reasons for the efficiency gain.

The current QSTP achieves a residual total phosphorus in the order of 0.07 mg/L. As illustrated in Figure 1 this historically has been achieved using a ferric dose of 1.7 mole Fe/mole P. This is considerably lower than the expected 6 to 7 mole Fe/mole P based on predictions from Biowin^{TM}, our experience and literature (Sedlack, 1991). As well ferric chloride, slaked lime at 50 mg Ca/L was also dosed at the plant. It was suspected the lime may be playing some part in the observed reduction in ferric chloride dose required.

A literature review was initially undertaken to explore reasons for the observed performance. Lime can remove phosphorus though calcium hydroxyapatite formation at high pH. However, the pH was much lower than required by this mechanism. Research by (Mishima 2017) suggested calcium when combined with iron can improve the chemical floc size and increase the precipitates surface positive charge. This allows for more phosphate removal by chemical adsorption.

An extensive series of jar tests were undertaken using treated effluent with a starting total phosphorus concentration of 9 mg/L. Iron and calcium were dosed at a range of different concentrations and the residual ortho phosphorus analysed. The same tests were also undertaken for alum. The pH was not controlled and was in the order of 7.5 as observed at the QSTP.

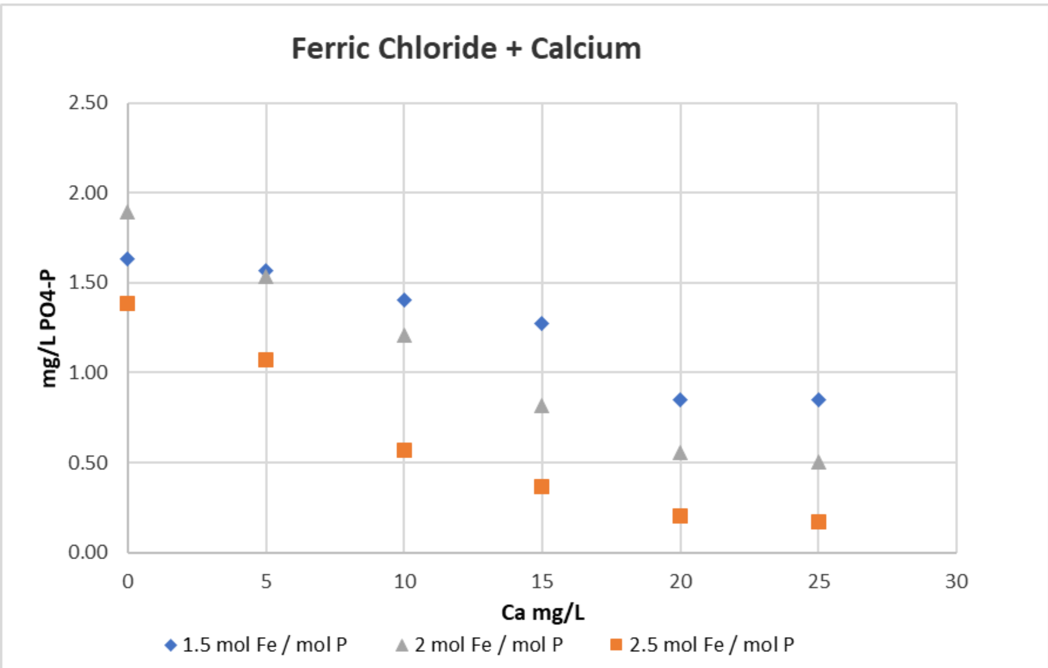
Figure 1: Typical Literature (Sedlak, 1991) and Biowin^{TM} Chemical Molar Dose Ratios for Ferric Chloride versus Effluent Residual Ortho Phosphorus including the Current Performance of QSTP



1.2 RESULTS AND DISCUSSION

The results from the jar testing for ferric chloride and lime co dosing are presented in Figure 2. They show residual ortho phosphorus levels after co-dosing ferric chloride with lime. Tests were also undertaken at a zero-calcium dose to compare to the traditional method for chemical phosphorus removal.

Figure 2: Residual Ortho Phosphorus for three different Ferric Chloride Molar Dose Rates versus Calcium (Ca) Dose after Settling.



The results confirmed actual plant data that there is a strong improvement in residual phosphorus if ferric chloride is co dosed with calcium. The research showed a much lower calcium dose of 20 mg/L is required compared to the 50 mg/L used in the current plant. This will further improve the cost saving benefit of this approach at QSTP. Similar testing with alum showed there was an equivalent improvement in the performance with calcium dosing. Results also suggest lower residual phosphorus concentrations are possible then that predicted by equilibrium chemistry. This is subject to further review, however if confirmed this may lead to improvements in the limit of technology residual concentration for chemical phosphorus removal.

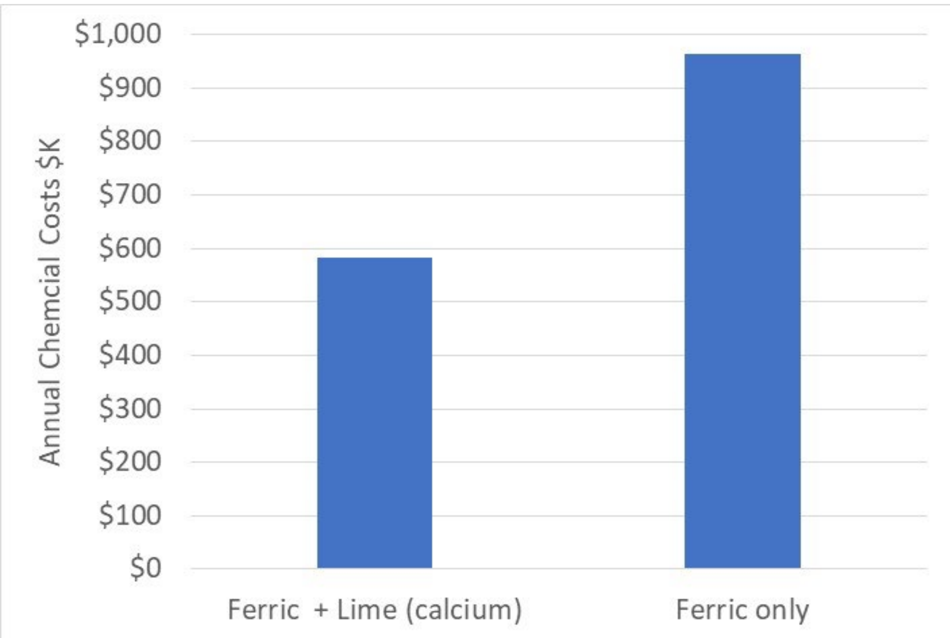
The significant finding of this research is that low residual phosphorus can be achieved (~ 0.1 mg/L) without the need for the traditional high iron molar dose rates above 7 mol P/mol Fe. A much lower molar dose rate in the order of half the traditional rate is required.

From a sustainability perspective a much lower iron dose has the following advantages:

- A lower effluent salinity is produced which improves the reuse potential.
- Less chemical sludge is produced lowering the biosolids production.
- The biosolids has a higher organic content.
- Offsets the need to add pH correction chemicals such as sodium hydroxide which are often needed for licence compliance.
- Results in less greenhouse gas scope 3 embodied carbon emissions as much less chemical is required.

For the 75,000 EP QSTP targeting a 0.1 mg/L total phosphorus, co dosing with calcium (slaked lime) will result in up to 40% savings in chemical costs ($379,000/year @ 75,000 EP) and 10 % saving in biosolids costs ($73,000/year @ 75,000 EP). Figure 3 compares the chemical costs for the 75,000 EP QSTP using the traditional and co dosing approach.

Figure 3: Chemical Cost at the 75,000 EP Queanbeyan STP for Ferric Chloride only versus co Dosed Ferric chloride and Hydrated lime

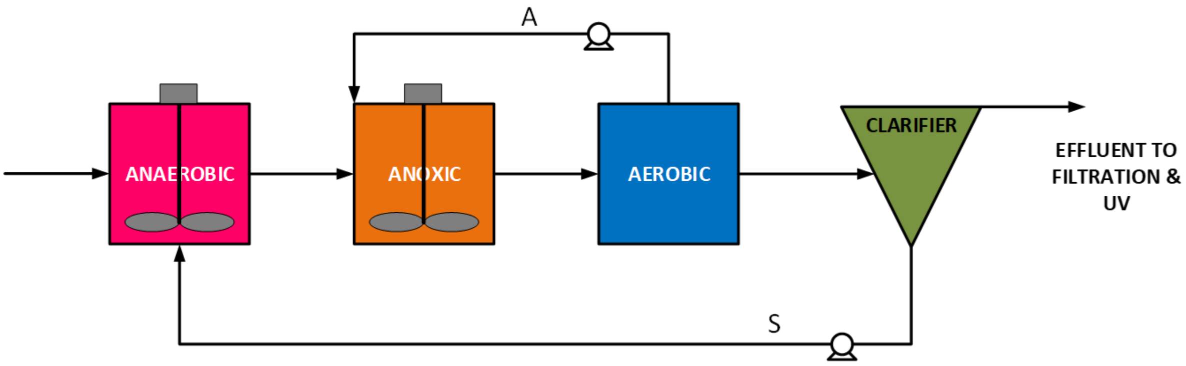


2. LOW ENERGY HYDRAULIC MIXING

2.1 INTRODUCTION

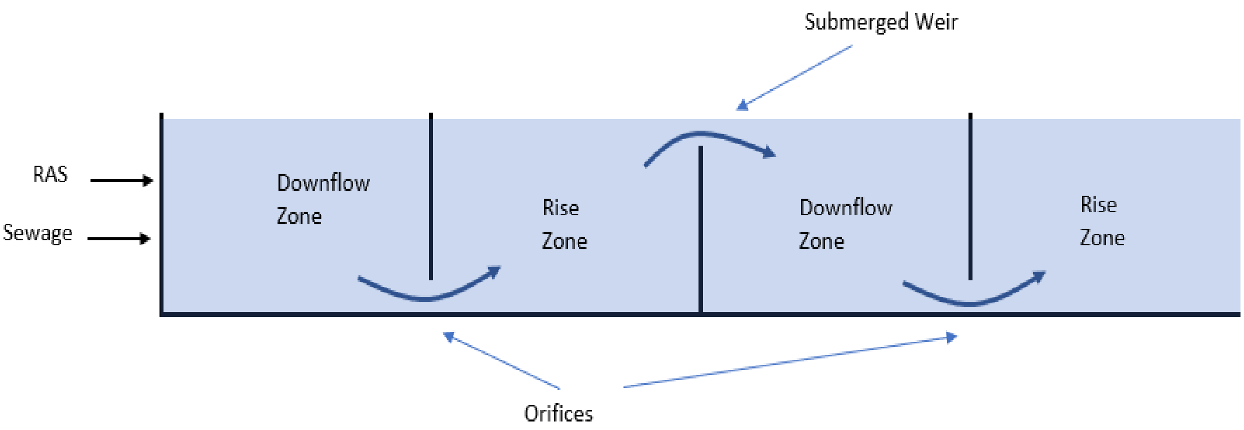
In standard BNR design there are unaerated zones which require mixing to avoid sludge settling occurring. This mixing power can be a large contributor to the total power consumption at BNR wastewater treatment plants when conventional mechanical mixing is used. The standard BNR configuration is shown below in Figure 4.

Figure 4: Standard BNR Design



To decrease the environmental impact at the upgraded treatment plant Beca Hunter H2O proposed hydraulic rather than mechanical mixing for the anaerobic zone at QSTP. Using conventional mechanical mixing the annual power consumption would be 20 kW and an annual cost of $35,000.

Figure 5: Hydraulic Mixing Configuration with Baffles and Orifices



Hydraulic mixing uses under and overflow baffles and underflow orifices to mix the sludge. The proposed configuration is shown in Figure 5. Essentially the process uses the “free” energy inherent in the incoming raw sewage and the return activated sludge (RAS) streams to achieve mixing. There is a slight extra energy use to pump these streams to a higher head to account for the extra head loss through the hydraulic mixing process.

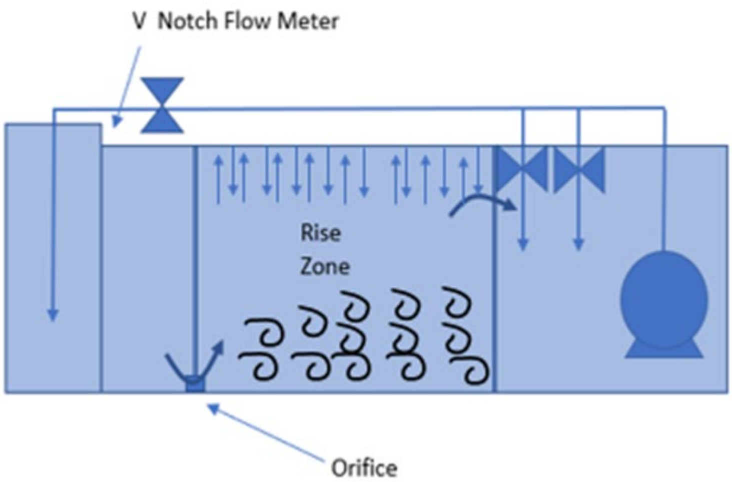
Beca Hunter H2O managed a pilot plant trial at QSTP to investigate the design criteria required to generate sufficient mixing using a hydraulic mixing approach.

The pilot plant was also used to develop a set of standard design conditions to allow future hydraulic mixing designs to be developed knowing the flow pattern.

The pilot plant was run in November of 2020 and was run by Liam Tamplin (Process Engineer), Craig White (Principal Engineer, Hunter H2O) and Joel Karibika (Work experience student). Below in Figure 6 is a photo of the pilot plant used.

Figure 6: Pilot Plant on Site

Figure 7: Section of the Pilot Plant outlying Key Equipment



It was postulated that hydraulic mixing would be influenced by the following parameters:

- Under flow orifice velocity. This provides energy for mixing.
- Sludge settling velocity. This can be calculated from Veslind correlations or measured onsite.

- Rise velocity through the rise zone. It needs to be high enough to overcome the sludge settling velocity.

The ability to adjust these key parameters was a consideration in the design of the pilot plant. As seen in Figure 6 and the sketch in Figure 7 the pilot plant was a steel tank designed and configured to investigate hydraulic mixing. It had a fixed speed submersible set of pumps and flow was controlled by returning flow to the pump chamber. A V notch flow meter at the entry to the inlet zone was used to set the recirculation flow. A square orifice was set up at the inlet zone. It had an adjustable plate to adjust the orifice area.

The key mixing parameters were adjusted by changing the following:

- Orifice velocity. The orifice area and or flow was adjusted to target a velocity.
- Flow rate was altered to change the orifice and rise velocities.
- Mixed Liquor Suspended Solids (MLSS) concentration was adjusted by diluting or thickening the QSTP MLSS to slow or speed up the sludge settling velocity.

There were a range of sample ports in the rise zone to assess the concentration of the MLSS after acceleration mixing by the orifice. A MLSS concentration probe was also used to assess if a sludge blanket was forming on the floor due to poor mixing.

Many combinations of flow and concentration were tested. The extremes of the testing regime are shown in Table 1. In each case the pilot plant was checked to assess if the MLSS concentration was uniform (indicating mixing is occur) and if any sludge blanket was forming.

Two key operating variables for any plant are flow and sewage load. Flow varies over the day to a minimum diurnal value overnight (typically 0.25 x average flow). The sewage load influences the MLSS concertation. At commissioning most plants will run at a much lower MLSS and as PE load increases over time the MLSS increases to near 4,500 mg/L

The worst mixing conditions are expected to occur at a combination of low diurnal flow and the lowest expected MLSS concentration at commissioning. At these conditions there is the lowest orifice velocity for mixing and the low MLSS concertation means the sludge settles more readily. For this reason, this condition was explored in some detail with the pilot plant to confirm mixing was adequate.

Table 1: Pilot Plant Testing Condition Range Extremes

Target Concentration (mg/L)	**Sludge Settling Velocity at Specified Concentration (m/s)**	**Simulated Flowrate (L/s)**	**Rise Rate at each Flowrate (m/h)**	**Orifice Velocity (m/s)**
4,500	1.5	200*	20	0.29
1,000	5.6	50**	5.0	0.1

*Average design flow, ** minimum dry weather diurnal flow (0.25 x average)

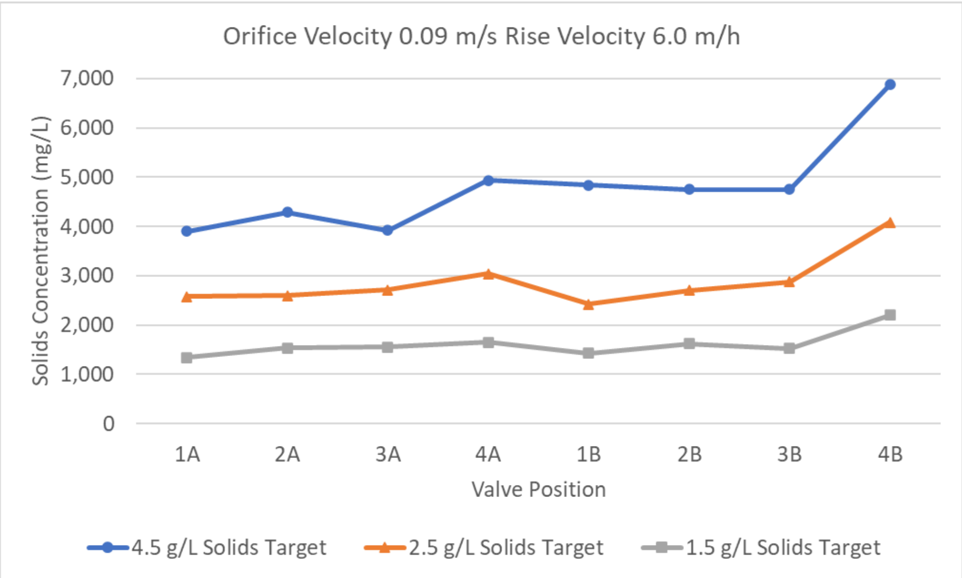
2.2 RESULTS AND DISCUSSION

The pilot plant was used to predominately explore the low flow regimes where mixing is difficult to achieve. Orifice velocity, rise velocity and MLSS concentration were varied in the plant and concentration assessed in the rise zone.

All the permutations of MLSS and orifice velocity showed no significant issues with mixing in the rise zone of the pilot plant even for low rates. The MLSS was relatively stable and there was little variance in concertation. Results from a sample run are shown in Figure 8. The sample locations (valve positions) are shown in Figure 6.

Some slight sludge accumulation was observed near the back corner of the rise zone. A MLSS probes was used to explore the sludge accumulating on the floor. The probe was lowered and when a sudden change in MLSS from the bulk value to a high value was measured, the level at which this occurred was recorded. Results for both the average and low flow conditions are shown in Figures 9 and 10.

Figure 8: MLSS Concentrations at an Orifce Velocity of 0.09 m/s and a Various MLSS values.



The results demonstrated that even at the very low flow conditions, only minor sludge accumulation occurred (70 mm over a 1,500 mm rise zone), indicating a relatively low orifice velocity near 0.1 m/s is sufficient for effective mixing even at a very low MLSS of 1,000 mg/L. A minor amount of accumulation in the order of 10% of the total mass is acceptable and can enhance fermentation.

Figure 9: Measured Sludge Accumulation on the Pilot Plant Base at ADWF Conditions with an Orifice Velocity of 0.29 m/s and a MLSS of 4,500 mg/L

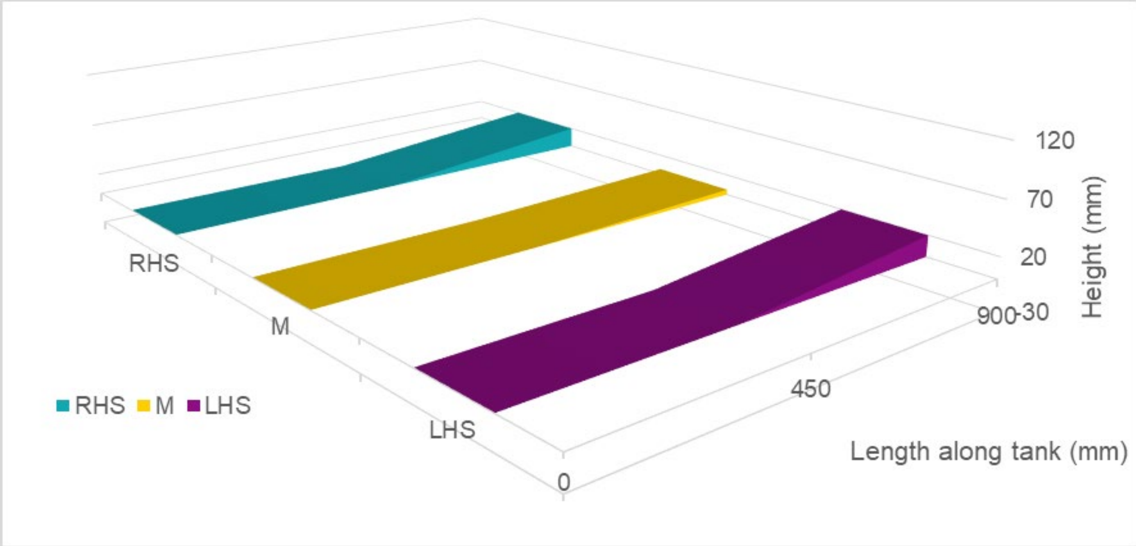


Figure 10: Minimum Diurnal Flow Sludge Accumulation on the Pilot Plant Base with an Orifice Velocity of 0.1 m/s and a MLSS of 1,000 mg/L

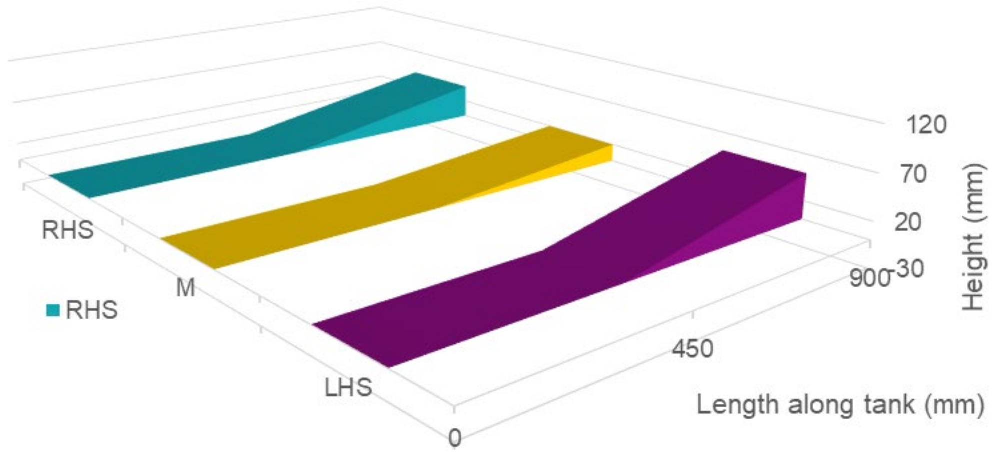


Table 3 shows the normalised power and scope 3 emissions for conventional mechanical mixing versus hydraulic mixing. The power savings are significant!

Table 3: Normalized Mixing Power use and New Zealand Scope 2 Emissions

Mixing Type	**Power Consumption (W/m^3)**	**Greenhouse Gas Emissions (Scope 2) (kg CO2-e/m^3/year)**
Conventional mechanical	8	8.4*
Hydraulic	0.28	0.29*

*Based on the scope 2 New Zealand emissions factor of 0.12 kg COD-e/kWh.

As well as the demonstrated power savings there are other treatment benefits of hydraulic mixing. Hydraulic mixing requires the installation of more baffles in the mixed zone compared to conventional mixing. A more compartmentalised zone has the following treatment advantages:

- Results in a greater organic food to microorganism (i.e. F/M) ratio. Higher F/M ratios select against filamentous bacteria resulting in a faster settling sludge. This can improve clarifier performance and reduce the size needed for new designs.
- If hydraulic mixing is used in anaerobic zones the more plug flow nature of the zone increases the rate of fermentation of soluble organics to short chain volatile fatty acids (SCVFA). SCVFA are necessary for biological phosphorus removal. Enhanced production of SCVFAs will support better phosphorus removal.

In terms of the capital costs of delivering hydraulic mixing, more cost is required to construct more baffles. However, this is offset by the reduction in capital and maintenance costs to run mechanical equipment. Our assessment of costs for QSTP identified there was no net capital cost penalty by adopting hydraulic mixing.

3 ENHANCED STORM TREATMENT

3.1 INTRODUCTION

Generally, licence requirements specify large storm flows which the treatment plants are required to accept. Typically, treatment plant designs would include a bypass system to reduce oversizing equipment for rare peak flow events. This bypass system allows only part of the flow (typically 3-times average dry weather flow (ADWF)) through the full treatment train and the balance is bypassed. There are generally two bypass techniques that are commonly used, being:

- Full plant bypass above 3 ADWF
- A solids contact bypass method. Part of the flow (3 ADWF) flows through the bioreactor and clarifiers. Excess flows (often between 3 and 6 times average flow) bypass the bioreactor and recombine with the bioreactor flow and the total passes through the clarifiers.

Both configurations are show in Figure 11. For the QSTP design there is no proposed primary sedimentation system.

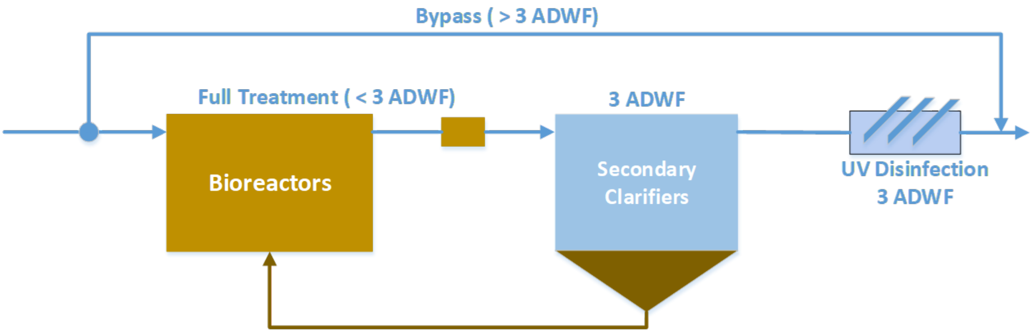
The solids contact bypass method effectively can double the flow a secondary clarifier can treat. By combining dilute sewage with the bioreactor solids effectively halves MLSS the clarifier operates at in wet weather. The much lower MLSS concentration increases the sludge settling velocity allowing for much higher hydraulic loading rates on the clarifier. Clarifiers treating activated sludge only are limited to 1.2 $m^3/m^2/h$, where solids contact process with a much lower MLSS can run up to 2.5 $m^3/m^2/h$.

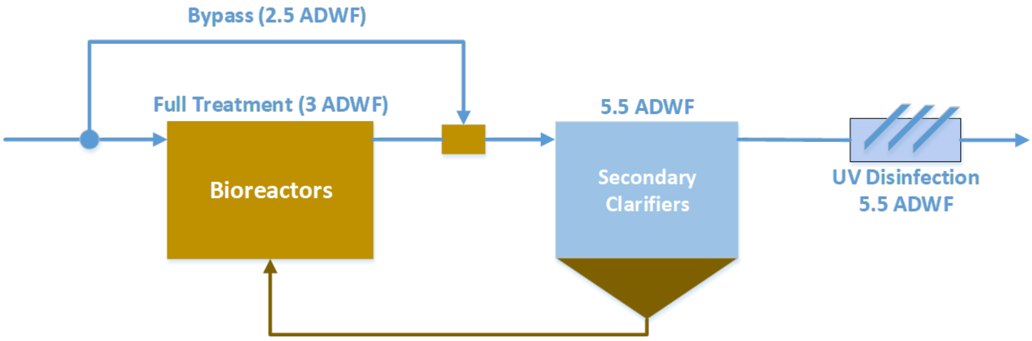
The solids contact bypass process is believed to be superior to the full plant bypass approach from an effluent quality perspective. The fact bypassed dilute sewage recombines with activated sludge from the bioreactor should mean flocculation of the solids and colloids in the sewage should occur. Once clarified enhanced particle capture should occur.

Although the solids contact bypass technique has been widely used there has been limited research to show if it improves effluent quality. Also, there is little design information on effluent quality performance to size disinfection systems such as UV that rely on low solids and organics levels (i.e UV transmittance (UVT)).

Beca Hunter H2O undertook an extensive set of onsite jar testing at QSTP to explore the performance of both bypass systems. A further research focus was to assess if building a much larger clarifier system (twice the traditional clarifier size) that passed all storm flows through the bioreactor and clarifiers was warranted.

Figure 11: Overview of the Flull Plant Bypass (1st figure) and Solids Contact Bypass (2nd figure) Approaches





Two sets of jar tests were undertaken to simulate both bypass methods which included:

- Full plant bypass. Simple blending of clarified effluent and simulated bypass sewage. The blend was tested for UVT.
- Solids contact bypass. Activated sludge samples from the plant and simulated bypass sewage were combined flocculated and settled. Effluent was decanted off and tested for UVT.

For the solids contact bypass, once the samples were combined, they were mixed vigorously for a minute (to simulate full pipe flow to the clarifier) and then slowly for five minutes before allowing the sludge to settle for 40 minutes. After 40 minutes a syringe was used to draw off the top layer of water to simulate a clarifier.

The simulated sewage was prepared using the following method:

- Raw sewage from the inlet works was used for raw sewage.

- Potable water was used to model the rain dilution.
- Raw sewage and potable water were blended in the necessary ratio to simulate the sewage rainfall event. For example, 4 times average flow would be 1 part sewage and 3 parts potable water.

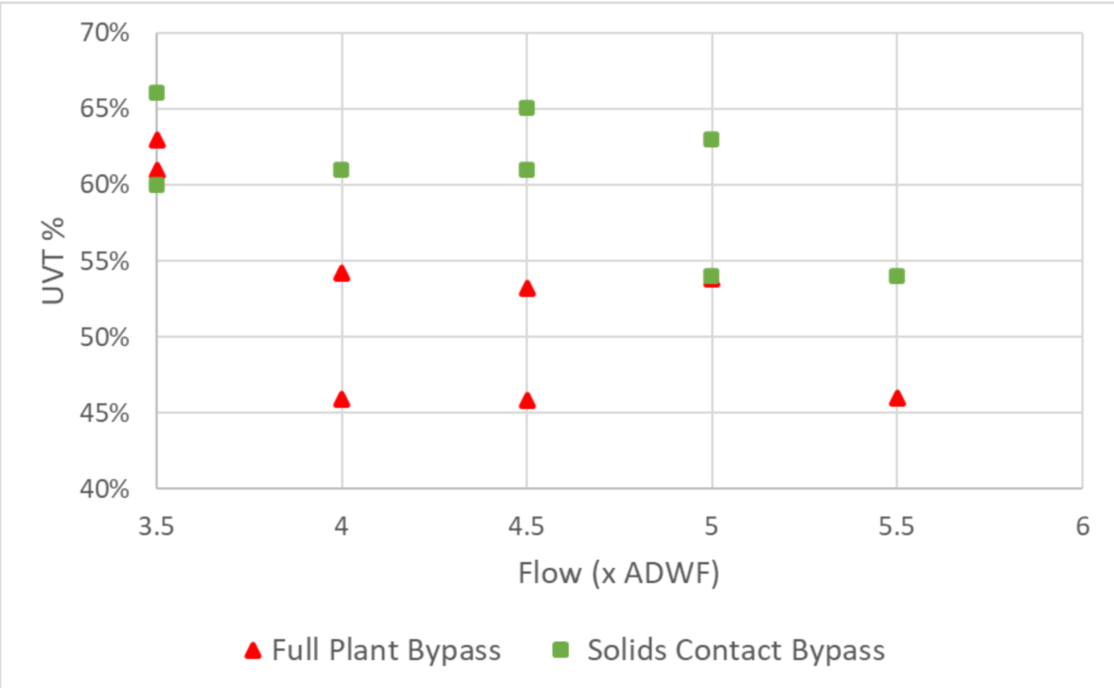
It was not acceptable to use treated effluent to dilute sewage as it contains unbiodegradable organics that are not present in rainwater.

The settled effluent from each of the jar tests were analysed for UVT. It measures the amount of UV light at 254 nm that can pass through 10 mm of water and is an indicator of soluble organics and particulate solids. UVT is also an important parameter for the design of UV disinfection systems.

3.2 RESULTS AND DISCUSSION

The jar test results from the assessment of the full plant bypass and the solids contact approach are presented in Figure 12. The results are presented from a flow of 3.5 up to 5.5 ADWF. Noting bypass occurs at 3 ADWF in both approaches. At flows below 3 ADWF all flow passes through the bioreactor and clarifiers with no bypass.

Figure 12: UVT at Various Bypass Flows for both the Full Bypass and Solids Contact Regimes



The results in Figure 12 clearly showed a solids contact bypass approach produced a higher UVT (i.e. less UV power consumption and better effluent quality) than the non-solids contact approach. This indicates activated sludge when contacted with storm water will rapidly adsorb colloids and particulate organics improving the UVT.

The interesting outcome from this research is the UVT for the solids contact process did not degrade significantly from the fully treated UVT level of 65%. This indicates, in terms of solids and organics removal, there is no real benefit in constructing much larger (twice the size) clarifiers that can treat all bioreactor flows with no bypass. For QSTP this saved ~ $8.3M (8% of project costs) in clarifier construction. The cost saving was attributed to not having to fully treat all storm water with no bypass.

4 SLOW THE OXIDATION DITCH DOWN

4.1 INTRODUCTION

As the wastewater discharge licence limits tighten, there is an increased demand for nitrogen and phosphorus removal. This is especially true for QSTP as the effluent discharges into a river upstream of the sensitive Lake Burley Griffin.

Oxidation ditches are well-known for excelling with respect to nitrogen removal and are often utilised when low effluent nitrogen limits are required. They are configured to have both aerobic and anoxic zones in racetrack configuration as shown in Figure 13. Oxidation ditches achieve significant nitrogen removal through the utilisation of a high internal recycle ratio known as the A-recycle, often up to 130:1 in an oxidation ditch. The high rate significantly improves the rate of oxidised nitrogen removal. By comparison, other BNR configurations utilise A-recycle ratios in the range of 5:1 to 20:1 and achieve higher effluent nitrogen levels.

Typical design practice is to keep the velocity at or above 0.3 m/s to keep all solids mixed and in suspension in an oxidation ditch. However, there has been no investigation to show if lower velocities are possible.

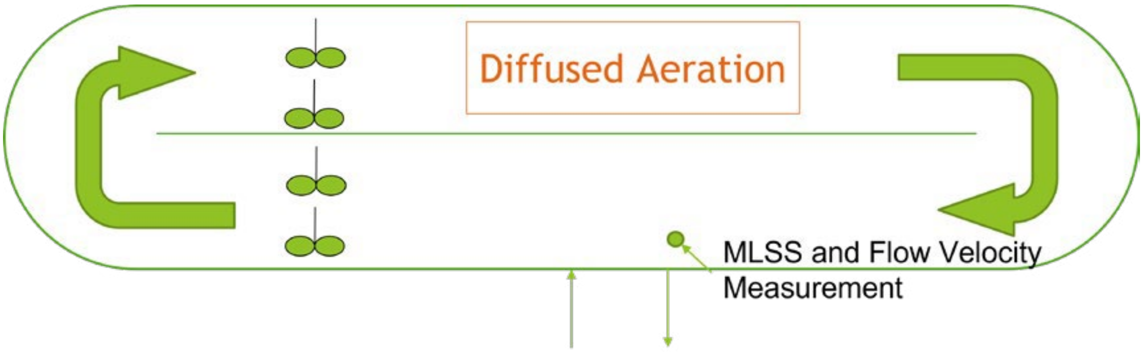
The high design velocity of an oxidation ditch means the dissolved oxygen (DO) used must be lower than traditional "box" bioreactor design. A lower DO is required to decay the DO to near zero in the oxidation ditch bioreactor to create the anoxic conditions for oxidized nitrogen removal.

Although high rates of nitrogen removal are achieved using an oxidation ditch configuration, it can suffer in colder climates where the lower DO used in the design can lead to elevated ammonia. If the velocity could be slowed the DO could be increased as there is more time for DO to decay in the fixed pathlength of the ditch. The higher DO would also benefit other process such as biological phosphorus removal which require DO to drive the uptake of phosphorus into bacteria cells. The lower velocities also reduce the power required to operate the plant.

Beca HunterH2O undertook an investigation at Mt St John 106,500 PE sewage treatment plant in Townsville QLD to explore how slow the oxidation velocity could be run before poor mixing occurred and sludge started to settle or stratify in the bioreactor. This was found by gradually slowing down the mixer speeds until settling of mixed liquor suspended solids was observed. The sludge suspension and stratification were assessed by monitoring the sludge suspended solids concentrations along the path length of the bioreactor using a MLSS probe. Below in Figure 13 are the locations where MLSS concentrations and flow velocity measurements were performed at the Mt St John oxidation bioreactor. The MLSS concentration was measured on the surface and 2 and 4 m below the surface respectively. A location was chosen for testing that was the furthest distance away from the mixers and diffused aeration grids. This location represented the highest risk of settlement if the velocity was not adequate to mix the sludge.

At the time of testing, Mt St John was only running at a MLSS of 2.5 g/L. This is quite low compared to other plants which are at design loading. Under the Veslind settling model, the sludge will settle quicker at lower concentrations. Therefore, this was a good situation to explore how low a velocity is possible.

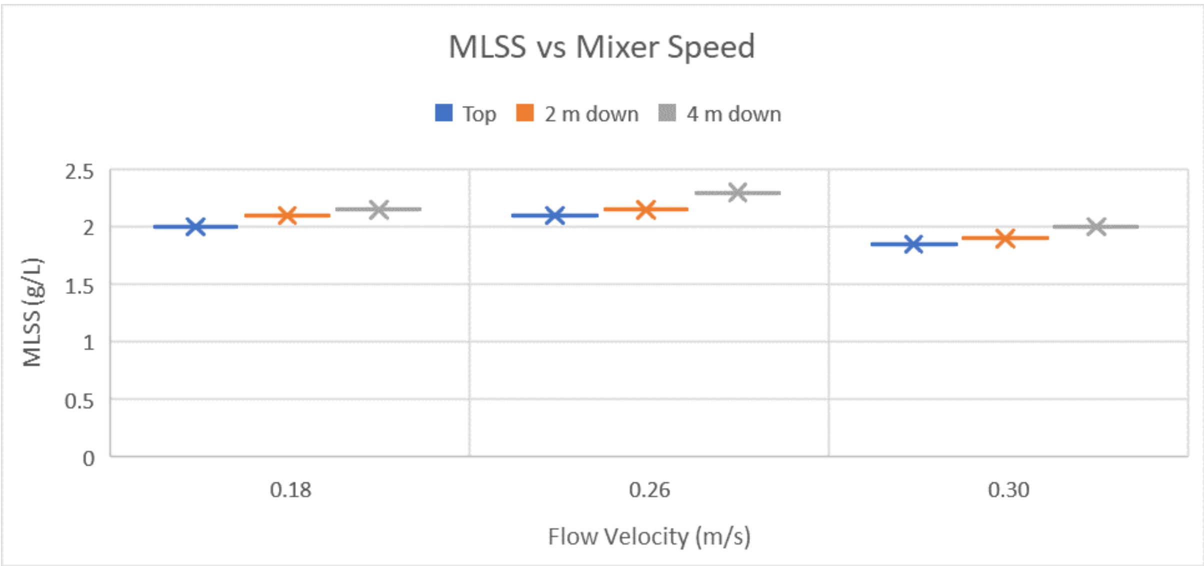
Figure 13: Oxidation Ditch Bioreactor General Arrangement and Testing Locations at Mt St John



4.2 RESULTS AND DISCUSSION

The results from the assessment of MLSS at the measurement location and three different bioreactor depths is shown in Figure 14. Results are presented for three separate channel velocities.

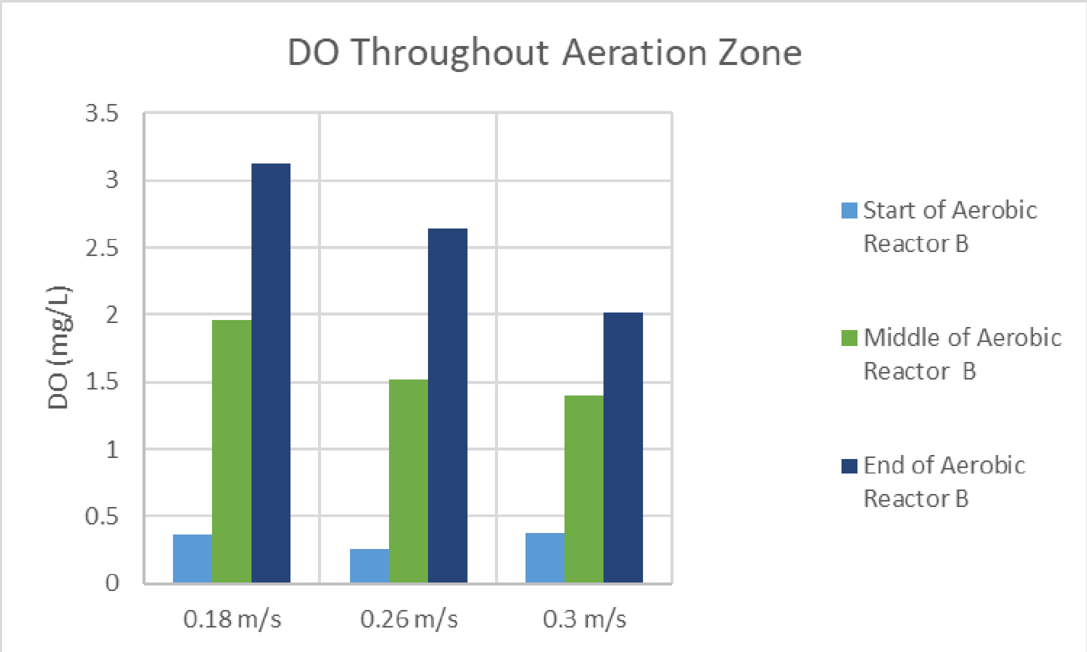
Figure 14: Sludge Settling Flow Profile at Varying Oxidation Fitch Flow Velocities



The results show there is no change in sludge concentration even for a very low channel velocity of 0.18 m/s. Visually, some minor separation was observed on the surface, however it was not significant. These results indicate the oxidation ditch could be run at a much slower velocity.

A key benefit of slowing the oxidation ditch is to increase the DO for the same aeration input. During the investigation the DO was measured at three locations along the diffused aeration zone and the results are presented in Figure 15. A significant increase in DO was observed for an overall lower energy use when mixing savings are considered.

Figure 15: DO Profile around the Oxidation Ditch at Varying Flow Velocities



The key advantage of slowing the ditch velocity is to improve DO. Higher DO will improve the ammonia removal performance in colder climates. These results show that slowing the ditch velocity by 50% is possible and it ensures the DO is similar to other “box” bioreactor designs in terms of the required design sludge age at minimum winter temperatures. Essentially this nullifies the nitrification (ammonia removal) disadvantage of an oxidation ditch and still ensures the overall high nitrogen removal benefit associated with their high internal recirculation rate. The slower rate will also assist in supporting biological phosphorus removal.

Operating at the much lower channel velocity will lower the power costs by 50% for channel mixing where diffused aeration and slow speed mixers are used. For QSTP this results in a significant power saving of $31,500 per year.

CONCLUSIONS

Beca Hunter H2O were engaged to design a 75,000 PE 4 stage Bardepho oxidation ditch process for QPRC in NSW Australia. In the design process, with the support of QPRC, we challenged some long-accepted industry design assumptions. Practical research was undertaken on a range of existing treatment plants. The aim being to remove unnecessary conservatism or knowledge gaps to improve the sustainability and effluent quality performance of BNR designs.

The outcomes of this research are globally applicable to both existing operating plants and new designs.

The findings of the research and key outcomes are summarised below:

- **Enhanced Chemical Phosphorus Removal.** A new approach for phosphorus removal was discovered which involves co dosing calcium and iron-based salts such as ferric chloride. This process reduces the required iron dose considerably resulting in a 40% saving in chemical costs compared to traditional single chemical iron salt dosing. There is also a 10% savings in biosolids costs due to reduce production of chemical sludge.
- **Low Energy Hydraulic Mixing.** Hydraulic mixing uses the inherent energy in the sewage and process flows to mix sludge in unaerated zones by using a series of baffles and orifices. This removes the need for mechanical mixing. A pilot plant was run to better understand how to ensure mixing occurs over the full flow regime. The pilot work allowed us to configure the orifices and baffles to mix the sludge in the most challenging operating conditions. The research identified a considerable 95% power and electricity scope 2 emissions saving over traditional mechanical mixing. The baffles needed for hydraulic mixing system will also improve effluent quality by enhancing biological phosphorus removal and selecting for a better settling sludge which improves effluent clarity.
- **Enhanced Storm Treatment.** The solids contact process uses a novel approach for storm treatment. Flow up to 3 ADWF passes through the bioreactor and excess storm flows bypass the bioreactor and recombine with the activated sludge from the bioreactor. The dilution of reactor solids considerably reduces the size needed for the clarifiers by 50%. Research was undertaken to assess the performance of this process in treating storm flows. The research showed the UVT (a measure of organic content) using this approach was not significantly impacted for flows up to 5.5 ADWF (with 2.5 ADWF bypass). Effectively the UVT was similar to a more conservative design where all storm flows are directed through the bioreactor (i.e. clarifiers are twice as large). For the QSTP design using the solids contact approach resulted in capital cost saving of $8.3M or 8% of the total project cost.
- **Slow the Oxidation Ditch Down**! Traditional design practice is to operate oxidation ditch processes at a channel velocity of 0.3 m/s to ensure mixing. However, the high velocity suppresses the achievable DO in the reactor. If the velocity could be slowed it would increase the DO and support better nitrification (ammonia removal) and phosphorus removal. Extensive testing was undertaken on a large 106,500 PE oxidation ditch running at a low solids concentration to assess how slow the velocity can operate at. The

investigation showed the speed could be significantly slowed from 0.3 to 0.18 m/s with no impact on mixing. This finding is significant for oxidation ditch designs in allowing designers and operators to further optimise effluent quality performance by using a higher DO with no significant energy penalty. There is also a significant mixing power saving of 50% if the lower velocity is used.

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