RESEARCH UNDERTAKEN TO IMPROVE SUSTAINABILITY AND REDUCE COSTS OF BNR PLANTS

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ABSTRACT

In designing the 75,000 Person Equivalent (EP) 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 two of the research projects with the biggest impact 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 EP) 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/EP per year reduction in operating cost) compared to conventional mechanical mixing. It also eliminated the need for ongoing maintenance costs for mechanical mixers.

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.

Throughout the design of this upgraded QSTP Beca Hunter H2O 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. Low energy hydraulic mixing as opposed to conventional mechanical mixing techniques.

Practical research was undertaken 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 Australia and internationally.

1.0 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 BiowinTM 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 BiowinTM, 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 through 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.

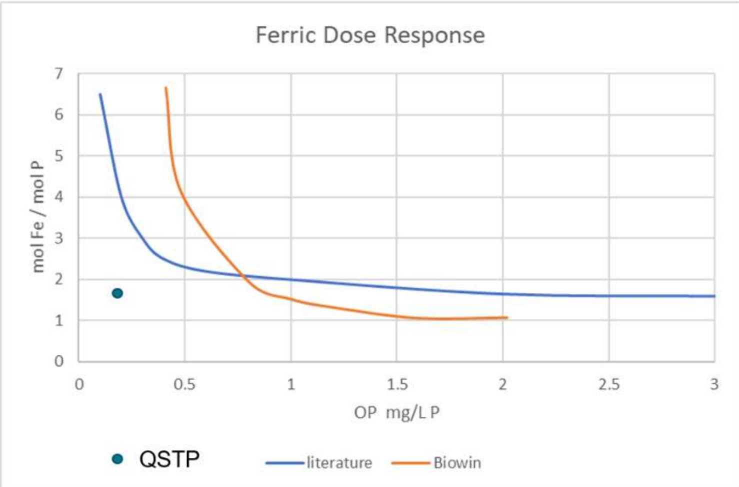


Figure 1: **Typical Literature (Sedlak, 1991) and BiowinTM Chemical Molar Dose Ratios for Ferric Chloride versus Effluent Residual Ortho Phosphorus including the Current Performance of QSTP**

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.

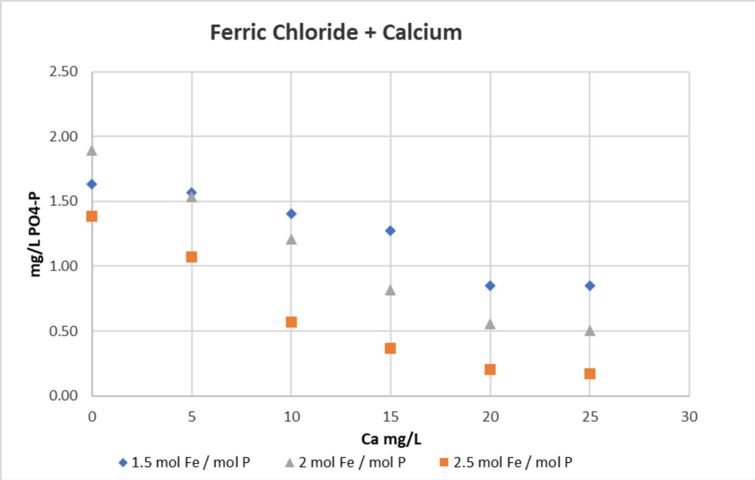


Figure 2: **Residual Ortho Phosphorus for three different Ferric Chloride Molar Dose Rates versus Calcium (Ca) Dose after Settling.**

The results from this jar testing confirm 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. Similar testing with alum showed there was a similar improvement in the performance with calcium dosing. Results also suggest lower residual phosphorus concentrations are possible then that predicted by equilibrium chemistry which may improve in removal limits of technology.

The key findings from this research are that low effluent phosphorus can be achieved with a fraction of the metal salt dose. From a sustainability perspective, a much lower iron dose:

- Lowers effluent salinity, which improves the reuse potential.
- Produces Less chemical sludge lowering the biosolids production.
- Produces Biosolids with a higher organic content.
- Offsets the need to add pH correction chemicals such as sodium hydroxide.
- 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.

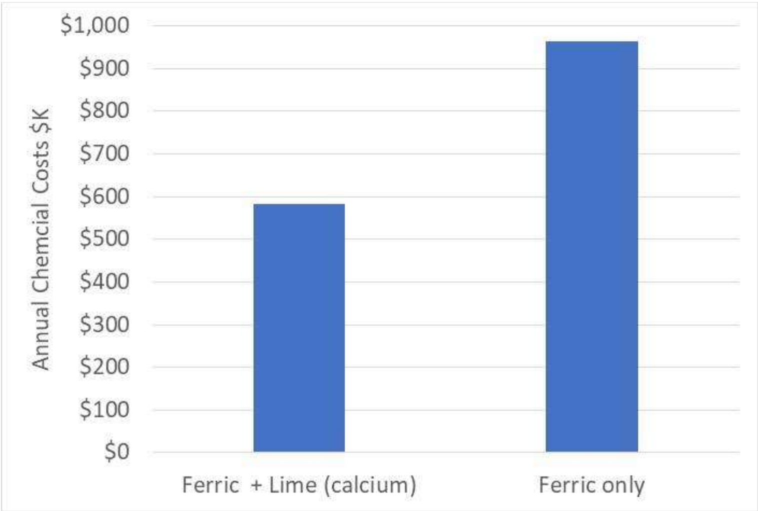


Figure 3: **Chemical Cost at the 75,000 EP Queanbeyan STP for Ferric Chloride only versus co Dosed Ferric chloride and Hydrated lime**

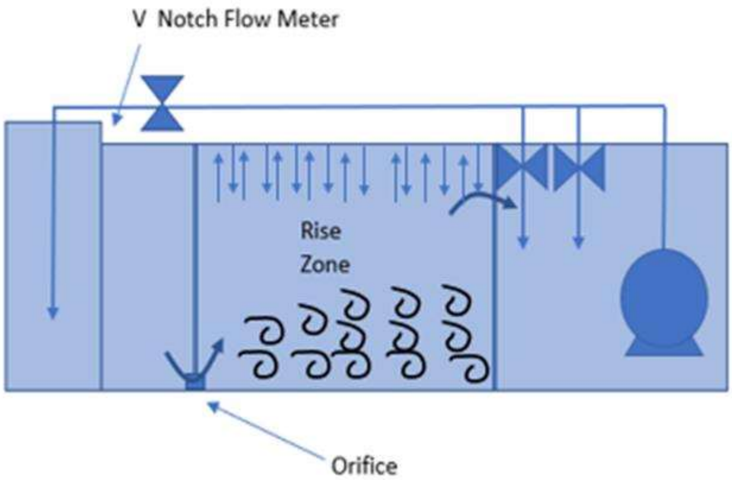
2.0 LOW ENERGY HYDRAULIC MIXING

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.

Using conventional mechanical mixing the power consumption would be 20 kW and an annual cost of $35,000. 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. Hydraulic mixing uses overflow baffles and underflow orifices to mix the sludge. 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 at QSTP and on future hydraulic mixing designs.



<u>Figure 6 & 7:</u> Section of the Pilot Plant outlying Key Equipment

It was postulated that effective mixing using the hydraulic mixing approach 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 7 the pilot plant was a steel tank designed and configured to investigate hydraulic mixing.

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.

A range a mixing conditions were tested throughout the duration of this pilot trial. 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.

2.2 Results and Discussion

The pilot plant was used to predominately explore the low flow regimes where mixing is difficult to achieve. The mixing effectiveness was judged using a MLSS probe to develop a sludge profile throughout the rise zone and check for sludge blanket height.

The pilot plant found that at all permutations of flow and concentration efficient mixing was achievable. 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.

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.

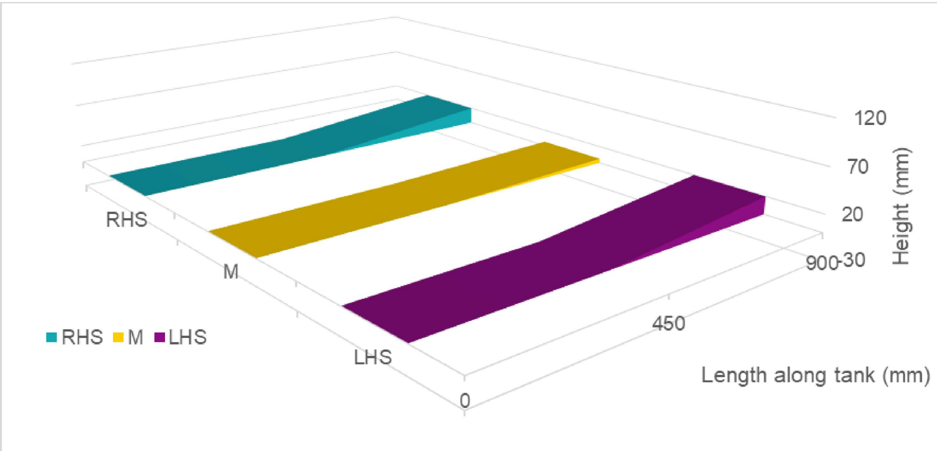


Figure 9: **Measured Sludge Accumulation on the Pilot Plant Base at ADWF Conditions with an Orifice Velocity of 0.29 m/s and a MLSS of 4,500 mg/L**

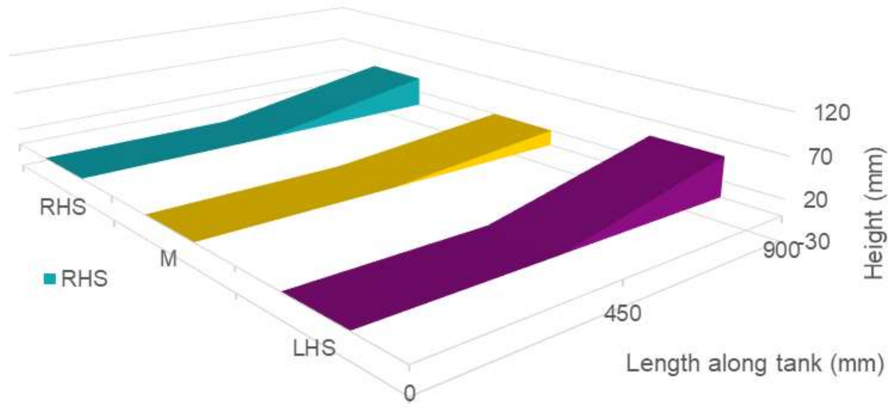


Figure 10: **Minimum Diurnal Flow Sludge Accumulation on the Pilot Plant Base with an Orifice Velocity of 0.1 m/s and a MLSS of 1,000 mg/L**

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 South Wales Scope 2 Emissions**

Mixing Type	Power Consumption (W/m^3)	GHG Emissions (Scope 2) (kg CO2-e/m^3/year)
Conventional mechanical	8	68.7*
Hydraulic	0.28	2.4*

**Based on the scope 2 Victorian Scope 2 purchase power emissions factor of 0.98 kg CO2-e/kWh.*

As well as the demonstrated power savings there are other treatment benefits of hydraulic mixing. The more compartmentalized nature of hydraulic mixing design 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.
- If hydraulic mixing is used in anaerobic zones increased rates of fermentation of soluble organics to short chain volatile fatty acids (SCVFA) which are necessary for biological phosphorus removal.

Our assessment of costs for QSTP identified there was no net capital cost penalty by adopting hydraulic mixing and only reduces maintenance requirements by removing mechanical mixers.

3.0 CONCLUSIONS

Beca Hunter H2O were engaged to design a 75,000 EP 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 from 2 of the research projects 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 reduced 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 removing the need for mechanical mixers. A pilot plant was run to better understand how to ensure mixing occurs over the full flow regime. 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.

4.0 REFERENCES

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