CHALLENGES AND INNOVATIONS IN DAIRY FACTORY WASTEWATER TREATMENT

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ABSTRACT

In recent years, Fonterra has expanded a number of their dairy manufacturing sites to increase the overall milk processing capacity of its New Zealand operations. A new dryer was installed at Fonterra's Pahiatua site in 2015 and a new milk powder dryer is being built at the Co-operative's Lichfield site. In order to accommodate the increased wastewater flows from the sites, new wastewater treatment plants (WWTPs) were required as part of the overall expansions.

Dairy factory wastewater has a number of characteristics that require careful management, including influent pH swings of 2-13, high fat loads and variable incoming organic and nutrient loads. Variations occur both on a seasonal and daily basis.

A number of innovations and features were incorporated into the Pahiatua and Lichfield treatment plant designs to overcome these challenges including:

- Use of a mixed liquor recycle to buffer pH swings
- Use of mechanical surface aerators with floating acoustic covers
- In-pond anoxic cycling to promote denitrification
- Use of dynamic process modelling to assess the sensitivity of the design to peak loads and aid in the development of risk management strategies
- Beneficial irrigation of waste activated sludge on to surrounding farms

Elements of this approach to wastewater treatment in the dairy industry could be adopted in a wider setting. For example in municipal plants treating an industrial wastewater component or municipal oxidation ponds that require upgrading to meet more stringent consent conditions.

KEYWORDS

Dairy Factory Wastewater Treatment, Pond Based Activated Sludge Systems

1 INTRODUCTION

In recent years, Fonterra has expanded a number of their dairy manufacturing sites to increase the overall milk processing capacity of its New Zealand operations. A new dryer was installed at Fonterra's Pahiatua site in 2015 to increase its production of milk powder. Following the Pahiatua expansion, a new milk powder dryer is being built at the Co-operative's Lichfield site. Construction is underway and it is expected to be processing milk in August 2016.

The Pahiatua factory is located in the Wairarapa approximately 2km from the township of the same name. The site consists of three powder plants with the most recent plant commissioned in 2015. The new powder plant was designed to process 2.5 million litres of milk per day, which effectively tripled the site's milk processing capability.

The Lichfield factory is located in the Waikato to the north of Tokoroa. The site currently consists of a cheese, whey and lactose plant and can process up to 3.2 million litres of milk per day. The addition of the new powder plant will increase the site's milk processing capability to approximately 7.6 million litres per day.

In order to accommodate the increased wastewater flows from the sites and to minimise the environmental impact of the expansions, new greenfield wastewater treatment plants (WWTP) were required.

Fonterra has traditionally used pond based activated sludge systems when implementing biological wastewater treatment. These systems combine the engineering economy of a pond with the performance of an activated sludge plant. However, increasingly stringent discharge consent conditions, particularly in regards to nutrient loads, noise and odour and Fonterra's commitment to limiting its environmental impact, has led to improvements in the traditional treatment approach.

This paper describes a number of innovations and features that were incorporated into the Pahiatua and Lichfield treatment plant designs to overcome these increasing challenges.

2 CHALLENGES FOR DAIRY FACTORY WASTEWATER TREATMENT

The challenges in dairy wastewater treatment are very much linked to the seasonality of the dairy industry. During winter there is little or no wastewater being produced by the factories for that 2-3 month period. Wastewater volumes and loads increase very rapidly at the start of the dairy season and biological treatment systems have to be robust enough to be able to maintain enough biological activity during the winter to start treating the wastewater when the new season starts.

The wastewater contains mainly dilute milk or milk products (milk fat, protein and lactose), with significant quantities of cleaning compounds and sanitizers, including a high sodium content from the use of sodium hydroxide for cleaning. Wastewater characteristics can change through the season due to product mix, but also daily due to Clean-In-Place (CIP) and production cycles. Unplanned events in the factory can lead to very concentrated product being discharged to the wastewater stream with a very high COD load, or high nitrogen or phosphorous concentration. Conversely, during the season nutrient imbalances may occur in the biological plants which can impact on the treatment plant performance.

The pH of the wastewater can vary greatly. Milk powder and butter plants tend to have strongly alkaline wastewater while the production of lactic acid in the wastewater from cheese, casein and whey plants makes the wastewater from these plants acidic. The wastewater pH can vary anywhere between 2 and 13 within short timeframes.

Providing a treatment system that can manage these varying conditions and provide reliable treatment to comply with consent conditions is a significant challenge. The approach to these challenges has been to include a number of treatment processes in the WWTP, the selection depending on the characteristics of the wastewater, the required effluent quality, cost and availability of land and predicted future quality standards.

3 TRADITIONAL TREATMENT APPROACH

3.1 IRRIGATION

Irrigation is the most commonly used method to treat dairy processing wastewater in New Zealand. An irrigation system is a complex treatment system involving elements of physical and biological treatment. Considerations in the irrigation design and operation are the volume requiring irrigation, the nutrient content (organics, fats, nitrogen and phosphorous), pH and metal ion and salt content.

The first step in any irrigation system is flow equalization and pH balancing. The primary purpose is to aid neutralization (where both acid and alkaline waste streams are present) and to equalize concentration fluctuations before chemical or biological treatment. Flow equalization is essential to optimize the DAF plant or an irrigation system.

Irrigation is currently used to treat wastewater directly from a site or after primary treatment (DAF). The irrigation system is operated at daily application rates between 15 and 25mm with a rotation period (start of an irrigation event to the start of the next event) of 16 to 20 days to allow conversion of the organic matter.

Soils must have good infiltration capacities. If the infiltration rate is too low then wastewater will pond on the surface of the land. If this happens wastewater can undergo anaerobic decomposition resulting in odours, acidification and damage to the plant cover. If infiltration rates are too high then the wastewater will spend insufficient time in the top soil to receive adequate treatment and groundwater contamination may occur.

Soil moisture plays an important role in irrigation management and is one of the challenges of any wastewater irrigation system. The soil moisture on an irrigation property is related to the soil moisture characteristics (saturation capacity, field capacity and drainage), weather conditions (rainfall, wind, evapotranspiration, temperatures) and irrigation. Irrigating soils that are too wet can lead to compliance issues (ponding and run-off) and damage to the farming system. Traditionally wastewater irrigation systems only have about 4 hours of storage, which means that all volume generated by the factory had to be irrigated almost immediately, resulting in a challenge to maintain a balance between irrigation and the farming operation.

The overall wastewater application is often driven by the annual nitrogen application rate. This rate is an integral part of an irrigation consent. In past years the focus has been shifting from a nitrogen loading rate (kgN/ha/y) to a nitrogen leaching rate. As leaching is difficult to measure, Overseer modelling is used to determine nutrient balances for the farms. The modelling looks at the whole farm and can make recommendations on the operation of the farming and irrigation system. Apart from nitrogen, phosphorous is becoming a major focus of any irrigation system. Achieving wastewater treatment using irrigation with a minimal impact on the environment is another significant challenge within a wastewater irrigation system.

3.2 BIOLOGICAL TREATMENT

A schematic of a typical biological wastewater treatment process implemented by Fonterra is presented in Figure 1 and each of the unit processes are discussed below.

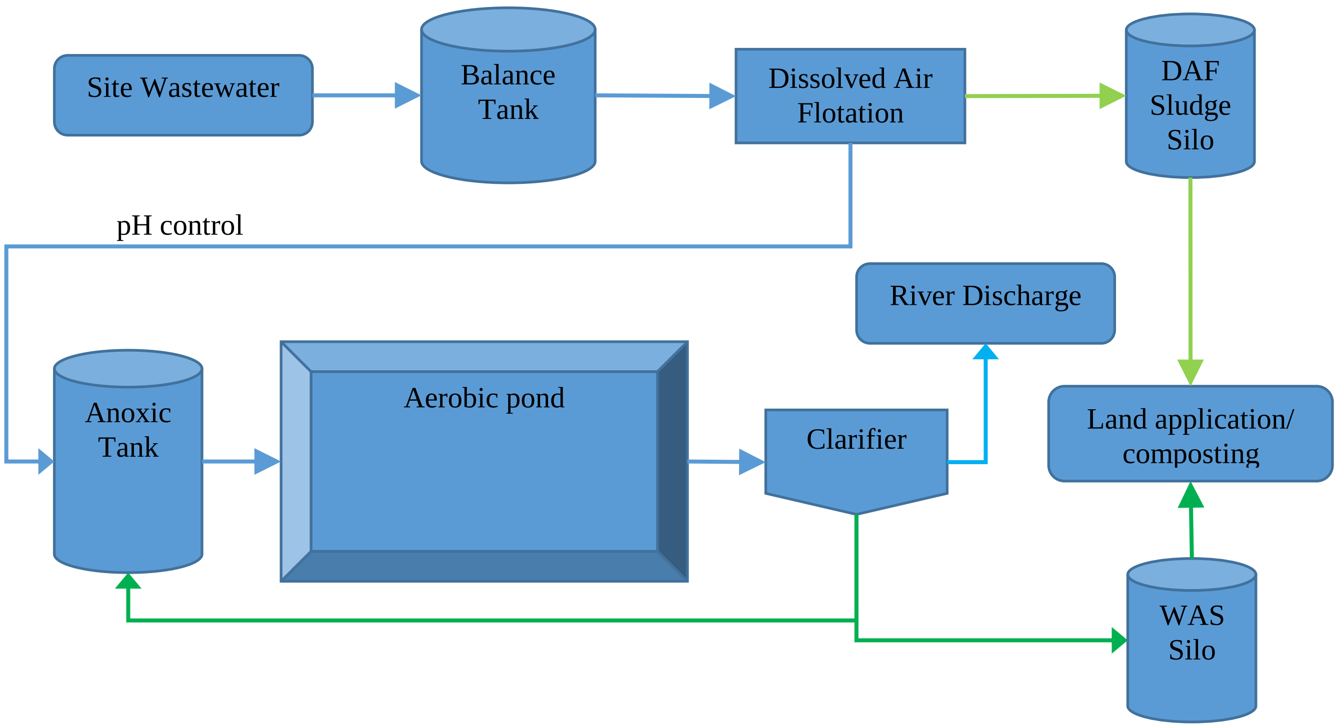

Figure 1: Typical Dairy Wastewater Treatment Process

DAF – Dissolved Air Flotation plants have been installed at a number of dairy sites to remove fat and protein. DAF plants are used as a primary treatment step for WWTPs as well as for irrigation systems. The advantages of DAF are that it has a small footprint and reduces the loads to a WWTP significantly. Removal of fat before irrigation is important to prevent "sealing" of the soil surface which can reduce infiltration. Disadvantages are high operating cost and difficulty of further treatment of the DAF sludge.

Anoxic Tank – The dairy industry tends to have nitrate rich wastewaters primarily from the cleaning chemicals used in the factory (e.g. nitric acid). For this reason, initial anoxic conditions in the form of an anoxic tank are favoured for denitrification. This often requires pH adjustment to achieve adequate denitrification rates.

Pond Based Aerobic System – A pond based aerobic activated sludge system has often been the preferred treatment process if space allows. The key advantage is that it provides a robust system that balances variable flows and loads. Typical hydraulic residence times are 4 to 8 days, with a sludge retention time between 20 and 30 days. Clarifiers have typically been used for secondary solids separation.

Aeration System – Most aeration systems used are based on floating mechanical surface aerators. Over the years they have proven to be reliable, with low maintenance requirements and a constant oxygen transfer efficiency over time. Downsides are that they are a significant contributor to the noise budget and on windy days spray drift can cause a nuisance.

Either land based treatment or biological treatment have traditionally been used exclusively. If sufficient land was available land based treatment has been the preferred treatment method. If no suitable land was available, biological treatment was implemented prior to discharge to a nearby surface water source. In more recent times, both systems have been used in combination, with biological treatment used as a contingency during wet weather when the soils are too wet to irrigate. During this time, the treated wastewater is discharged to surface water.

Variations of the traditional treatment approach including a number of innovations were adopted at the Pahiatua and Lichfield sites as described below.

4 INNOVATIONS IN TREATMENT APPROACH

4.1 AERATION SYSTEM SELECTION

Typically Fonterra uses floating mechanical aerators for all pond based activated sludge plants as discussed in Section 2 and this was the approach taken at the Lichfield WWTP.

However, the Pahiatua WWTP was required to comply with very stringent boundary noise and odour conditions and hence an alternative approach was adopted. The WWTP consent application was based on using submerged aeration to meet night time boundary noise limits of 45 dBA, which would not be possible with conventional surface aerators.

During preliminary design, the following submerged aeration systems were reviewed:

- Blowers and floating aeration laterals with suspended submerged diffusers
- Submerged bottom mounted self-aspirating mechanical aerators

Whilst such systems were likely to comply with the noise limits, concerns were raised about access and maintenance, odour risk from dead zones in the pond, risk of pond liner damage and the limited track record of such systems in New Zealand.

To minimise risk, an alternative solution using mechanical surface aerators with acoustic covers, motor hoods and silencers was developed and a variation to the consent conditions granted. Onsite noise measurements were taken from the covered aerators after installation (Table 1).

Table 1: Noise Measurements of Surface Aerators

Parameter	Standard 75kW Aerator	75 kW Aerator with Noise Attenuation
Noise level at 40m	58 dBA	50 dBA

The addition of the acoustic cover, motor hood and silencer resulted in an 8 dBA reduction when compared with the supplier stated noise level from a standard 75 kW aerator.

The use of acoustic covers on mechanical surface aerators (Figure 2) was a first in New Zealand and has aided in the site successfully meeting the overall noise performance requirements set out in the resource consent.

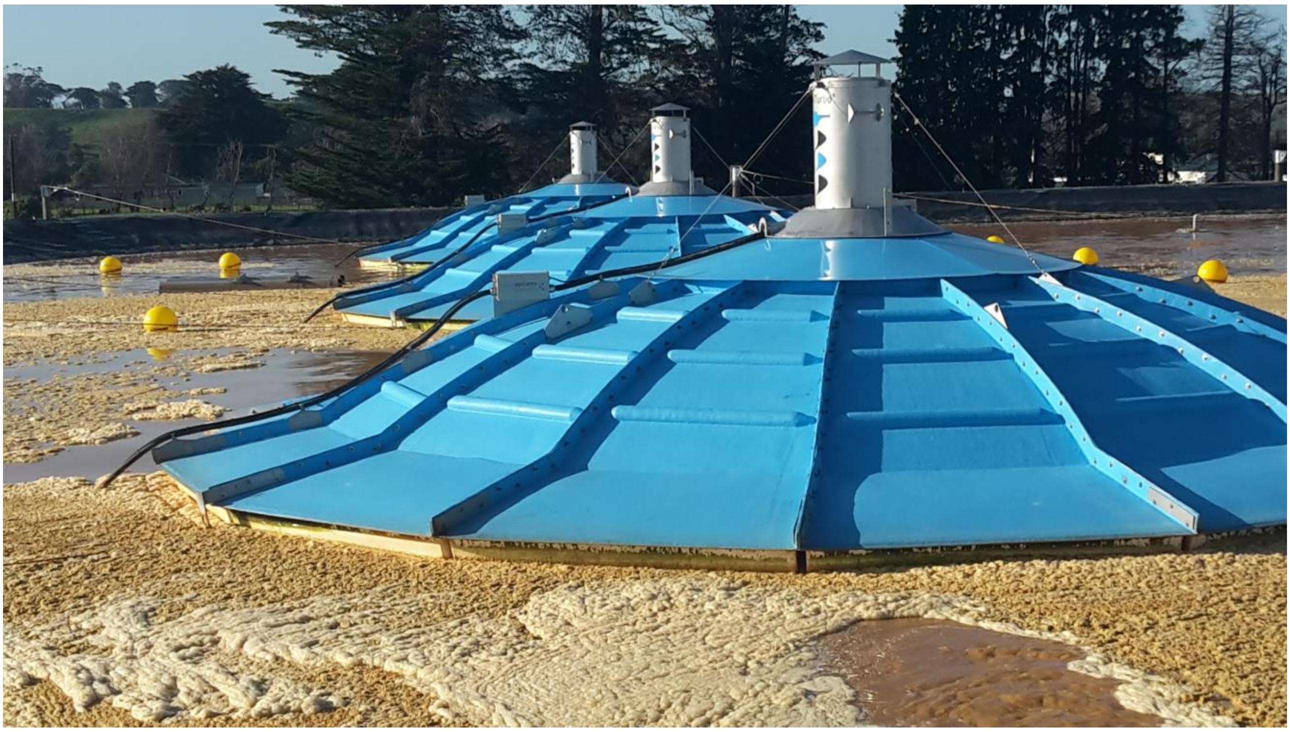

Figure 2: Floating Surface Aerator with Acoustic Cover and Motor Silencer

4.2 PEAK LOAD MANAGEMENT

Developing a reasonable and representative design basis for a treatment plant is an important step in the design process. Under estimating design loads can result in performance issues such as odour and not achieving target effluent quality, whilst over estimating design loads can add unnecessary cost to the overall system.

Dynamic process modelling was undertaken during the design phases for both the Pahiatua and Lichfield treatment plants to aid in the development of a reasonable design basis. At both sites the treated wastewater is applied to land and hence short term excursions outside of the target effluent quality can be tolerated much better than a plant that is discharging to surface water. Dynamic modelling was used to simulate how the plants were likely to respond to short-term peak nitrogen and COD loads outside of the proposed design envelope. To generate the influent dataset, wastewater monitoring data from similar sized powder plants at the Darfield site was used to approximate the load for the new powder plants at the Pahiatua and Lichfield site.

The outputs from the models suggested that the treatment systems were able to sustain short term overloads without causing significant degradation to the effluent quality. The predicted immediate DO response at Pahiatua was a decline from $2 g/m^3$ to about $1.2 g/m^3$ (Figure 3). The low DO was sustained during the high load period but recovered over the following 4 days and the MLSS reduced back to the preload conditions.

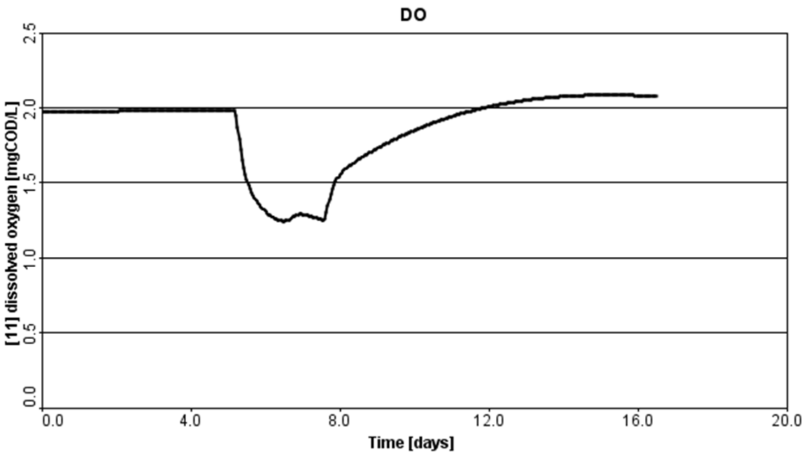

Figure 3: Predicted D.O. Concentration During Peak Loading

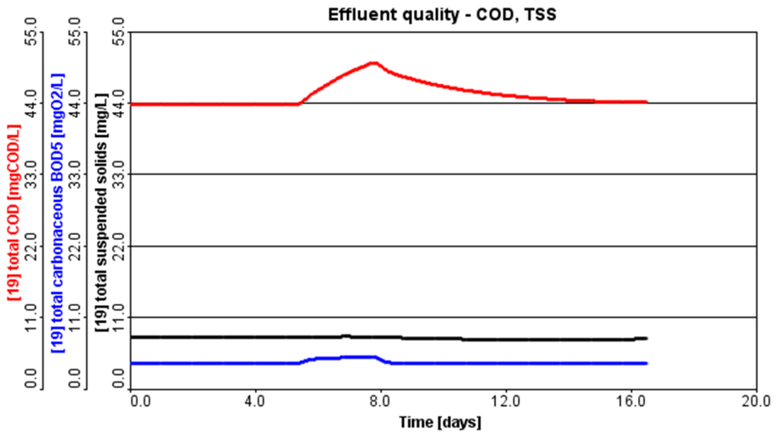

Figure 4: Predicted Effluent Quality During Peak Loading

Predicted effluent COD concentrations showed a marginal increase to about 50g/m^3 within the 2 day high load period (Figure 4). There was essentially no predicted change in the BOD or TSS effluent quality.

On the basis of the dynamic modelling, the design of the treatment processes were based on the proposed 95 percentile loadings rather than absolute peak loadings.

Dynamic modelling is a useful tool to assess the sensitivity of a design to peak loading and can be used to aid in risk management.

4.3 ANOXIC CYCLING

In pond anoxic cycling is a technique implemented by Fonterra to promote nitrogen removal at a number of its sites with two pond systems. During an anoxic cycle, all aerators in the primary pond are turned off to reduce dissolved oxygen (D.O.) concentrations to a level that is suitable for denitrification to occur. After a set time period, the aerators restart and operate to maintain a D.O. setpoint until the next anoxic cycle is initiated. The number of anoxic cycles that take place each day is typically operator determined and may vary throughout the season. The second pond is continuously aerated to maintain an overall positive D.O. concentration in the system.

Anoxic cycling was considered for nitrogen removal at both the Pahiatua and Lichfield WWTPs. The specific site conditions at each WWTP determined which process was selected:

- The Pahiatua site had limited space available and was in close proximity to sensitive neighbours. In addition, the resource consent for the site stipulated that the treatment pond was to maintain a positive D.O. at all times. This site was therefore better suited to an anoxic tank which has a compact footprint and is able to be retrofitted with a cover and odour treatment system in the event that odours from the site become an issue.

- The Lichfield site had space available for a two pond system and was in a relatively remote location. This site was therefore better suited to an in pond anoxic cycling process, eliminating the need for a separate anoxic tank.

Careful control of the cycling is required to achieve optimal nitrogen removal and to prevent performance issues such as odour and poor settling sludge.

During the design of the Lichfield WWTP, dynamic modelling was used to predict the optimal anoxic cycle duration and overall aeration requirements for the system in order to more consistently meet the nitrate targets in the discharge. The anoxic cycle time is currently being tuned during commissioning of the plant.

4.4 BALANCING pH SWINGS

Wastewater from a milk powder plant can vary between pH 2-13 with an overall bias towards more alkaline conditions. For denitrification to occur successfully, a pH range of 6-9 is typically required. To achieve ideal pH conditions in the anoxic tank for denitrification, pH balancing or neutralisation may be required. Sulfuric acid dosing to control pH was considered upstream of the Pahiatua anoxic tank. However, Fonterra were seeking to eliminate the chemical handling and associated health and safety risks as well as the capital and ongoing operational costs of an acid dosing system.

As an alternative, the anoxic tank was enlarged and the mixed liquor recycle rates increased above that required for denitrification in order to provide additional pH balancing (Table 2). The increased capital and operating costs from the upsizing was offset by the savings from eliminating a sulfuric acid dosing system.

Table 2: Anoxic Tank and Mixed Liquor Recycle Sizing

Parameter	**Units**	**Original Design**	**Enlarged for pH Balancing**
Anoxic Tank Size	m^3	1800	2200
Mixed Liquor Recycle Rate	m^3/hr	108	510

The variation in pH in the raw wastewater and the anoxic tank over the course of a day is shown in Figure 5. The pH trends show that the mixed liquor effectively balances the pH to between 8-10. Plant performance data indicates that denitrification is successfully taking place at this pH range, with nitrate-N results of less than 1mg/L being achieved in the clarifier discharge.

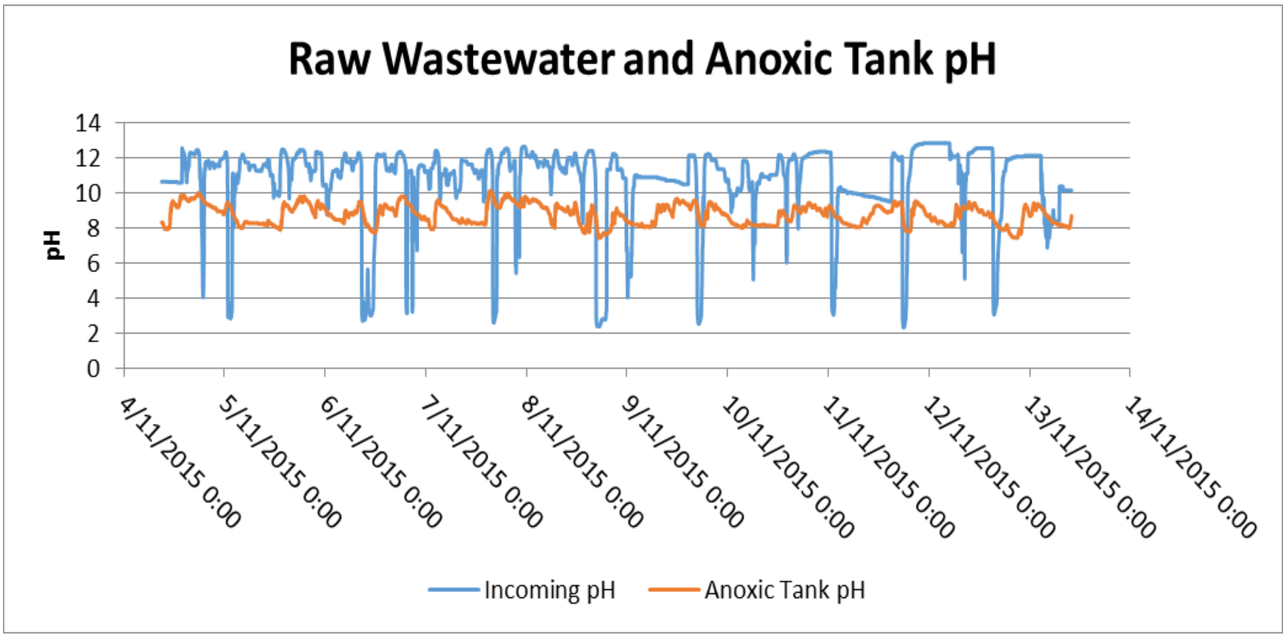

Figure 5: Raw Wastewater and Anoxic Tank pH over the course of a day at the Pahiatua Site

4.5 STORAGE POND AND MANAGEMENT SYSTEMS

Both sites use a storage pond to store treated wastewater before irrigation to assist in the management of the irrigation systems. During normal operation treated wastewater from the pond is irrigated onto the farms on a daily basis, subject to weather and soil conditions. During the spring and autumn the volumes of wastewater produced may exceed the volume that can be reliably irrigated on the farms. The excess treated wastewater during wet weather is stored in the pond until it can be irrigated in a drier period.

The Lichfield irrigation system consists of Fonterra owned irrigation farms as well as pod irrigation on third party farms. The development included an expansion of the irrigation on Fonterra owned land previously used as forestry, but now converted to pasture. The irrigation system is based on a fixed sprinkler irrigation system. The system is split into four blocks that can be irrigated simultaneously. Each of the blocks has 34-37 zones. Four zones of up to 2.5ha each are sequentially irrigated every day at a peak flow of 165 m^3/hr.

The third party farms are usually not irrigated until late September/early October. Whilst sufficient hydraulic capacity is available on the Fonterra owned farms to irrigate all treated wastewater, storage is used in the first two months to be able to defer irrigation during extreme wet weather events. From October onwards both Fonterra and third party land is used and the storage will be used further during extreme weather. The aim of the management philosophy is to utilise the storage pond as much as possible. If done well the storage pond will be full by mid-December and then the stored water can be irrigated during the drier summer months.

The volume of water stored is monitored daily. A simple spreadsheet model has been developed to allow operators to compare the actual pond level against the expected level for a typical year. Operators monitor the pond level against the model, shown in Figure 6, and use this to guide the irrigation volumes.

The storage pond at Pahiatua is required to maintain a DO concentration of 0.5mg/L at all times. During design, the requirement for supplementary aeration and mixing within the storage pond to prevent odours and algal growth was assessed. Given the large surface area of the pond, turnover in the pond, low BOD loadings (30-50kg BOD/ha.day) and prevalent windy conditions, the requirement for aeration and mixing in the pond was considered unnecessary. Retrofit solutions were considered as part of the design and can be implemented in the future should algae growth become a problem. To date DO concentrations in the storage pond have been at or near saturation with typical concentrations being 6-8mg/L. No odour problems have been reported.

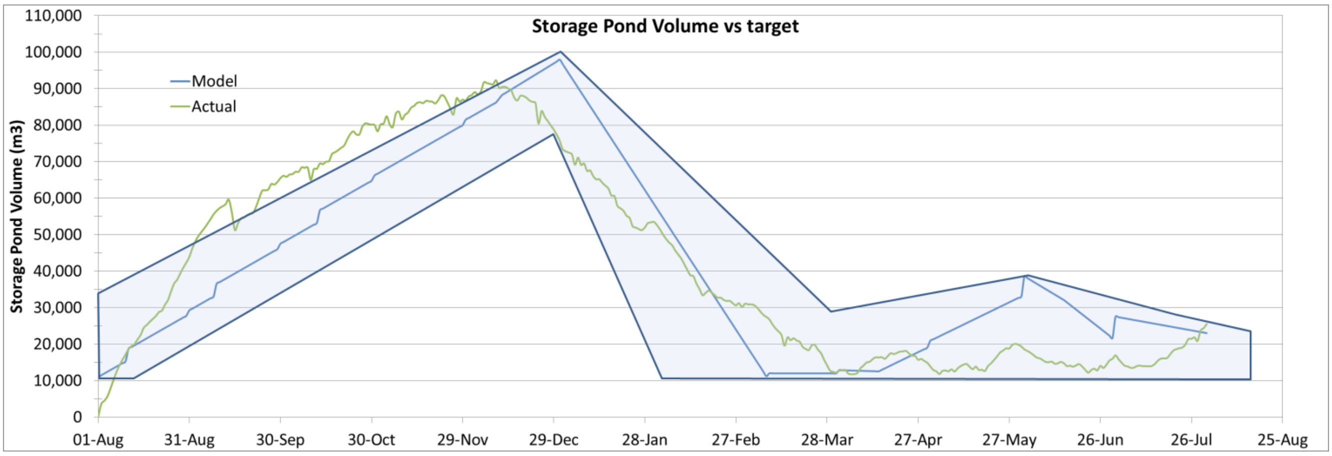

Figure 6: Pahiatua Storage Pond management Model with actual levels

4.6 APPLICATION OF BIOMASS TO LAND

The biological treatment of wastewater removes a large portion of nutrients before irrigation on the nearby Fonterra owned dairy farms. Therefore, fertilizer applications would be required to maintain pasture growth rates and quality on the farms. The waste biomass from the biological treatment process contains nitrogen and phosphorus that can be beneficially applied to land as a slow release fertiliser, thereby eliminating fertiliser costs and reducing costs for the transportation and composting of biomass.

The biomass wasting requires additional management when compared to a conventional WWTP. The nitrogen loading from irrigated wastewater, cow shed effluent (Pahiatua only) and fertiliser is strictly controlled by the resource consent. To optimise pasture growth and reduce costs to transport and compost biomass from the WWTP, some of the biomass is added to the wastewater before irrigation. Nitrogen loadings on each paddock from wastewater, biomass and cow shed effluent are monitored daily and as a cumulative annual loading to ensure they are close to the allowable limits without exceeding them before the end of the season. These loadings are used in annual Overseer modelling. Although Pahiatua increased its production capacity from 1.3 million litres of milk to 3.8 million litres, the nitrogen loading has been reduced.

At Pahiatua the treated wastewater and biomass are blended together in a dedicated silo prior to irrigation to a fixed concentration as set by the operator. A mixer was installed in the silo to promote a homogeneous mixture and prevent solids settling in the silo. At Lichfield the biomass will be injected into the irrigation lines directly to achieve the required biomass concentration. During wet weather the biomass addition can be stopped completely to manage the soil's treatment capability. Either the excess biomass is exported, or retained in the ponds for irrigation during drier times.

The operation of the Lichfield irrigation system will have essentially the same average whole farm nitrogen leaching (determined by Overseer modelling) as before the new dryer development, even though the site will increase its milk processing capability from 3.2 million litres of milk to 7.6 million litres per day. This is possible due to a combination of the increase in irrigation area and a cut-and–carry operation. The management of the biomass is similar to Pahiatua, where a portion will be irrigated and the remainder is thickened using a gravity belt thickener and exported.

The biomass concentration can be increased or decreased during the season as actual nutrient loadings are compared to projections for the rest of the season. Last season at Pahiatua approximately 90% of the waste biomass from the WWTP was blended with treated wastewater and irrigated onto surrounding farm land. The remaining 10% of biomass was dewatered to 15-16% dry solids using a decanter centrifuge and transported offsite to a composting operation. The application of waste biomass to land has saved Fonterra at Pahiatua in excess of $320,000 in operating costs (cartage and polymer) over a season of operation.

The other cost savings is in replacing fertilizer applications. Typical fertilizer applications of Urea/Nitrogen (92kgN/ha/y), Superphosphate/P (43 kgP/ha/y) and muriate of Potash/K (70kgK/ha/y) would cost around $225 per ha per year. The application of WAS onto the Fonterra Pahiatua farms had a benefit of around $45,000 in fertiliser cost.

5 DISCUSSION

Whilst dairy factory wastewater presents a number of unique challenges, parts of the approach taken to treatment could be applied to a wider industry such as municipal systems treating a trade waste component or oxidation ponds that require upgrading to meet more stringent consent conditions. The wider applicability of the innovations discussed in this paper are summarised in Table 3 below.

Table 3: Wider Applicability of Dairy Factory Treatment Processes

Innovation	**Wider Applicability**	**Discussion**
Acoustic Covers	Yes	Surface aerators with acoustic covers could be adopted in municipal or industrial pond activated sludge systems that are required to meet strict noise boundary conditions.
Peak Load Management	Yes	Dynamic modelling can be used to assess the sensitivity of a system to peak loading and aid in the development of management strategies. This approach is more applicable for treatment plants discharging to land where short term excursions in effluent quality are better able to be managed than a system discharging to surface water.
In-pond Anoxic Cycling	Yes	Anoxic cycling could be adopted in existing treatment processes in order to remove nitrate from the system. Careful control of the cycling is required to achieve optimal nitrogen removal and to prevent performance issues such as odour and poor settling sludge.
Balancing pH Swings	Maybe	Municipal wastewater does not typically experience large swings in pH and hence pH balancing is not typically required. pH balancing using a mixed liquor recycle could be applied to other industrial wastewater treatment processes or a municipal plant treating a trade waste component.
Storage Pond Management	Yes	A large scale storage pond could be implemented for systems that have limited irrigation capacity during wet weather. Treatment is required prior to long-term storage to prevent the development of odours.
Application of Biomass to Land	Maybe	This approach could potentially be applied to other industrial wastewaters, however may not be feasible for municipal treatment plants. The human pathogen content of municipal wastewater and the use of the irrigation land (e.g. pasture for stock, crop growth etc) may prevent or limit the application of biomass from a municipal treatment plant to land.

6 SUMMARY

The Fonterra Pahiatua and Lichfield dairy factories have recently been expanded to significantly increase the milk processing capabilities of each site. In order to accommodate the increased wastewater flows from the sites and to minimise the environmental impact of the expansions, new greenfield WWTPs were required. A number of innovations were incorporated into the Pahiatua and Lichfield treatment plants including:

- Selection of floating surface aerators with acoustic covers. This allowed a tried and tested treatment process to be utilised whilst meeting stringent boundary and odour conditions.
- Use of dynamic process modelling to assess the sensitivity of the design to peak loads and aid in the development of risk management strategies.
- Use of an increased mixed liquor recycle to balance pH swings and eliminate the need for a sulfuric acid dosing system.
- In-pond anoxic cycling to promote denitrification. This has eliminated the need for a separate anoxic tank.
- The use of a storage pond to store treated wastewater during periods of wet weather for irrigation during drier times.
- Beneficial irrigation of biomass on to surrounding farms. This provides a nitrogen source for the farms and reduces biomass treatment costs.

ACKNOWLEDGEMENTS

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REFERENCES

Bamford T., Shaw R. and Daly J (2016) 'Innovations in Water Reuse and Recycling in Dairy Processing' OzWater Conference 2016.