An evaluation of current and potential technology for the treatment of farm dairy effluent in New Zealand

Assessing the potential to use anaerobic digestion and sequencing batch reactor technology as an alternative method of treatment of farm dairy effluent

A thesis

submitted in partial fulfilment

of the requirements for the degree

of

Master of Environmental Sciences

at

The University of Waikato

by

Kendal Buchanan

2019

Abstract

In order to keep up with social and consumer demands the regulations surrounding nutrient losses from dairy farms in New Zealand are becoming harsher. A way in which dairy farms can reduce the loss of nutrients is to improve the management of farm dairy effluent (FDE). FDE management can be improved by adding a treatment. This treatment may be chemical or biological.

The objective of this research was to develop a method of biological removal of nutrients from farm dairy effluent that enables more efficient management of those nutrients. The system that resulted (BioClean) was a five-stage system including; solids separation, anaerobic digestion, an enhanced biological nutrient removal sequencing batch reactor, sand filtration and UV disinfection.

Modelling of the BioClean system and current methods of FDE handling and treatment, found that BioClean outperformed all current technologies (two pond treatment, land application and ClearTech) in the removal of nitrogen from the liquid fraction (average removal of 98%). The removal of phosphorus and potassium from the liquid fraction were not found to be sufficient for discharge to waterways with average residuals of 13 mg/L and 772 mg/L (Table 32) respectively. Removal of *Escherichia coli* by BioClean was found to be vary significantly with scenario variation (from a mean of 0 cfu/100ml to 16,260 cfu/100ml).

Analysis of the model found that variation in results could potentially be explained by the model simulation. Therefore, even though scenario and treatment variation were found to be statistically significant ($p<0.05$) in most cases, the cause of that variation can not confidently be linked to either the treatment change or variable that changed with regards to scenario differences.

Economic analysis of the addition of the BioClean system to a New Zealand dairy farm found that if the desired levels of nutrient removal could be achieved the addition of the BioClean system to a dairy farm was to be viable. The system was found to reduce daily running costs in comparison to the typical land application system due to pumping only the liquid fraction of FDE after solid separation a short distance.

Future research into the BioClean method through a lab-scale trial was recommended to improve the accuracy of the model and optimise the operating system.

Keywords

Farm dairy effluent, enhanced biological nutrient removal, nitrogen removal, phosphorus removal, sequencing batch reactor, anaerobic digestion.

Acknowledgements

This study would never have been possible without the support of many people.

I would firstly like to thank my head supervisor Dr Mark Lay and supporting supervisor Dr Graeme Glasgow.

I would like to thank my friends and family for your support and encouragement to get me through to the end.

Table of Contents

Table of Figures

Table of Tables

Chapter 1. Introduction

1.1 New Zealand Dairy Farming

New Zealand dairy farming accounts for approximately 3% of the worlds milk production of milk and New Zealand is the largest exporter of dairy products world-wide. The North Island of New Zealand accounted for 79% of dairy herds in the 2017/18 and 59% of dairy cows, contributing 56% of milk solids (DairyNZ, 2018). These statistics demonstrate the vast variability in dairy farming systems used across New Zealand and between the North and South Island of this country. The North Island is typically home to smaller more traditional New Zealand dairy farms working on the pasture based-system. Whereas the South Island has seen rapid growth in the dairy industry over the past 20 years and is home to larger herd sizes and more modern, intensive farming. Although the ‘typical’ farm for the North and South islands there are different there are farms of all sizes on both islands.

There is a scale in the New Zealand dairy industry used to assess the intensity of the farming system being used. This scale helps farmers to identify what system they are running and therefore enables easier benchmarking against similar systems. The scale ranks farm systems from System 1 – 100% grass fed with no supplementary feeding to system 5 - where cows are fed high levels of supplementary feed year-round.

According to QuickStats by DairyNZ there were approximately 4.99 million cows milking in the 2017/18 season with an average herd size of 431 cows. These cows graze 1.76 million ha and the average farm size is 151 ha. It is also estimated that 46,000 people are employed within the New Zealand Dairy industry (DairyNZ, 2018)

1.2 Trends in New Zealand Dairy Farming

New Zealand dairy farming has been intensifying since the 1970’s. This extended intensification period has resulted from large gains in the productivity of; the animals, the land (soils and pastures) and farm systems. Rapid intensification of the New Zealand Dairy industry from the late 1970’s to 2000’s lead to initial concerns over the environmental impact of dairying in New Zealand. This intensification was led by a rapid increase in cow numbers which occurred simultaneously with a reduction in dairy farm numbers resulting in larger herd sizes. Herd sizes increased by 82% from an average of 121 cows per farm to 220 cows per farm over the 1977-1997 period (Longhurst, Roberts et al. 2000).

Coupled with the intensification of the industry, there has also been growth in total dairy cow numbers over this time. Dairy cow numbers have steadily increased from approximately 3 million in 1981 to approximately 5.5 million in 2006. As can be seen in Figure 1this growth has not been matched by any other livestock sector. Deer numbers are the only other sector to have grown, whilst beef cattle have remained steady and sheep have declined significantly (70 million to 40 million from 1981 to 2006) (Andrew van Bunnik, Jennie Francke et al. 2007).

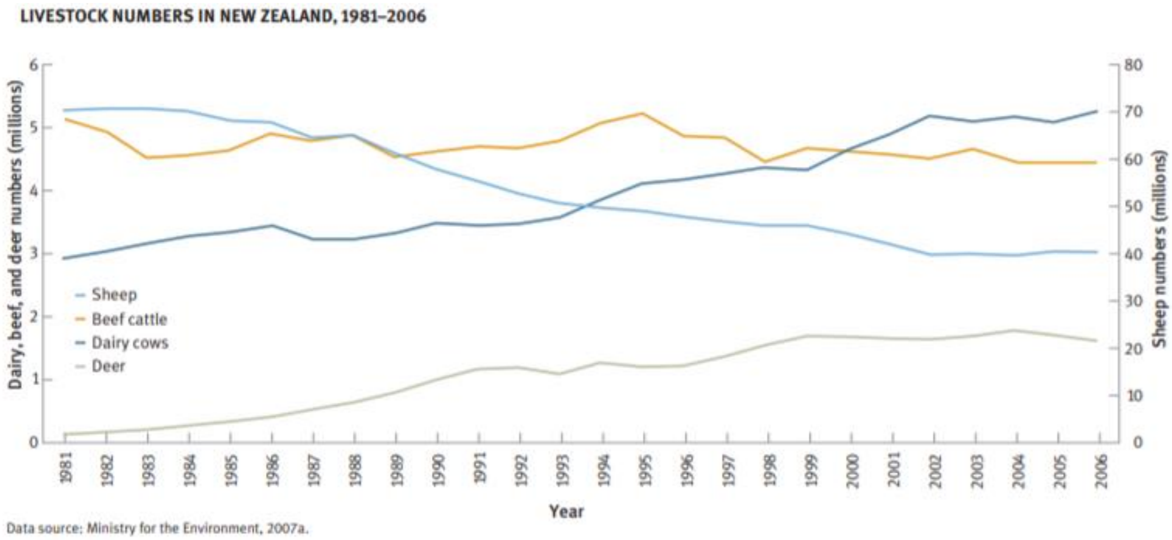

Figure 1: Livestock numbers in New Zealand from 1981 until 2006(Andrew van Bunnik, Jennie Francke et al. 2007).

Since 2000 the dairy industry has further increased in intensity and in size. The average herd size in 2016 was 416 cows, a significant increase from 251 cows per herd in 2000 (Longhurst, Rajendram et al. 2017). However, over this period land area covered by dairy farming (and agriculture and horticulture as a whole) has reduced.

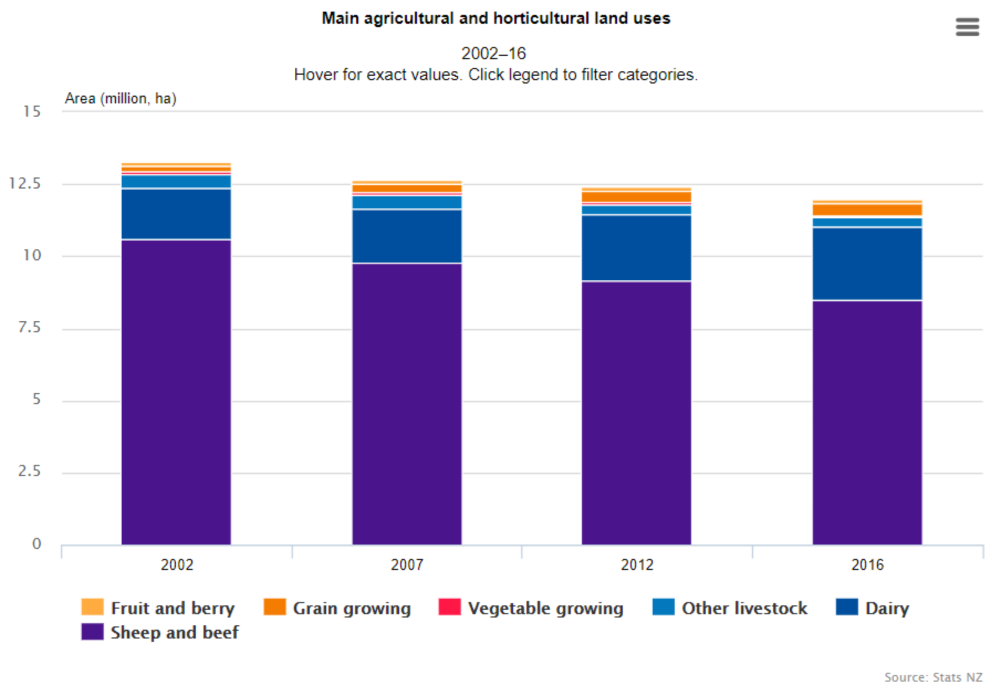

Figure 2: Land use change over time by area (Statistics New Zealand 2018).

The growth of the dairy industry for this period was driven by irrigation developments making marginal (mainly Canterbury) land significantly more productive. These conversions have typically been large scale, to enable the cost of irrigation to be justified by economies of scale. These large-scale dairy farms are typically more intensive, due to irrigation enabling higher stocking rates (as a result of reliable seasonal pasture growth). Intensification of the dairy industry has generated a more efficient farming system resulting in a positive economic effect. On the contrary, this intensification has also been associated with negative affects including accelerated environmental degradation.

The Resource Management Act (1991) gave the responsibility to regional and district councils to monitor and manage nutrients in the environment. This piece of legislation coupled with research done at the time drove regional councils to push farmers to change their farm effluent management systems. At the time this legislation was implemented, farm dairy effluent was primarily treated in a two pond (anaerobic and aerobic pond) system and then discharged to waterways (rivers, drains, wetlands). Research at the time directed regional councils to move farmers away from two pond treatment of farm dairy effluent and discharge to land application of farm dairy effluent (FDE)(Longhurst, Roberts et al. 2000, Roach, Longhurst et al. 2001). Rates of FDE application were typically set at 150 or 200 kg N/ha/yr. for application to land. Councils initiated the move to land application by making it an action that did not require consent when discharge to water required a costly consent.

Intensification of the dairy industry coincided with an increase nitrogen fertiliser use and imported feed supplements (maize silage and palm kernel expeller) (Longhurst, Rajendram et al. 2017). These two major changes to the dairy farm system resulted in severe negative environmental impacts. Increased application of nitrogen(N) to land is related to increased loss of N from the root zone (leaching). Increased intensity on dairy farms has seen high levels of N being applied to land, far exceeding 150 kg N/ha/yr. (generally accepted maximum application level). Greater losses of N from root zone (leaching) resulted, which leads to eutrophication of waterways. Although pasture productivity has increase with new technologies, intensification has exceeded productivity gains, this generated the need to import feed. To manage introduced supplements and higher stocking rates, feed pads, wintering barns and standoff pads have become increasingly common, assisting increased feed consumption efficiency. These structures increase the capture of excreta which contributes to an increase in FDE capture resulting in an increased load of effluent applied to land. This can lead to the oversupply of nutrients to land/pastures. The environmental degradation brought about by the continued intensification of dairy farming has stimulated tougher regulations in this area. In 2011 the National Policy Statement for Freshwater Management (2011) (NPSFM) was implemented, this was followed by the Sustainable Dairying: Water Accord in 2013. The NPSFM builds on the RMA (1991) and requires councils to set water quality limits and then action a plan to monitor and manage water quality to ensure those limits are met and maintained. Over time, understanding of the environmental impacts of this degradation has been heightened. This has resulted in and continues to influence both regulations, the action of farmers and other industry members.

To meet incoming or recently set standards in regional plans, in some cases large system changes need to occur. Handling of FDE is a significant challenge environmentally on dairy farms as FDE is such a nutrient rich substance. This provides both positives and negatives. Farmers aim to utilise the nutrients in the

FDE as they are a ‘cheap’ fertiliser. However, when applied incorrectly these nutrients can be easily lost to the environment.

When FDE is applied to saturated soils, or at rates in which the water holding capacity of the soil is exceeded, this increases the potential for by-pass flow to occur. By-pass flow is where in this case, FDE moves rapidly though large macro pores. This reduces contact of FDE with soil, and in turn reduces the filtration or removal of nutrients. Where by-pass flow occurs, the FDE runs through the soil profile similarly to runoff. Ponding occurs where FDE is applied to saturated soils or at rates such that the soil moisture deficit is surpassed. Ponding results in increased potential for run off. Both of these scenarios lead to elevated levels of nutrients entering the aquatic environment.

1.3 Environmental Impact – Water

On average a New Zealand dairy farm uses 70 litres of water per co per milking for the wash down of the cowshed yard, milking platform and milking plant (DairyNZ 2019). The average herd of 416 cows in 2016, required 29,120 litres of water without accounting for stock drinking water. Cows drink varying amounts of water depending on the composition of the feed they consume yet average about 40 litres per day (Stewart and Rout 2007). This would therefore increase the daily water requirement of the 416-cow dairy farm by a further 16,640 L. In some parts of New Zealand farmers pay per litre of water (Canterbury) and other parts a consent is required for use over 15,000 L (Waikato Regional Council. 2013). Growing social concern over water use is increasing pressure for water use efficiency on dairy farms. This may potentially lead to further regulation of water use on dairy farms in the future, building on the current Sustainable Dairying: Water Accord and government regulations.

A driver of the growing social concern for water use and water quality is the increasing levels of eutrophication in rivers and lakes throughout New Zealand. Eutrophication occurs where high levels of nutrients are found in a water body. Eutrophication can lead to reduced dissolved oxygen and increased algae production. High levels of nutrients in water under the right conditions (warm, with high levels of dissolved oxygen) enables rapid growth of algae, resulting in the production of large volumes known as algal blooms. This rapid growth utilises the dissolved oxygen in the water and can result in the development of anoxic (low to zero oxygen) conditions reducing the ability for aquatic life to survive. Waterways and bodies are reaching eutrophic levels in many areas across New Zealand. The impact of nutrient discharge (due to runoff and leaching) is enhanced by the removal of water from waterways and water bodies for irrigation and other uses. By decreasing the volume of water, the concentration of nutrients in the water is increased, therefore, exacerbating the problem. Where irrigation is concerned, irrigation increases the water content of the soil and therefore increases the potential for macro pore flow or run off due to saturated soils, further increasing the impact.

Over the years the dairy industry has progressed and changed. In the future changes to current systems will be required for many farms to improve (reduce) environmental impact and comply with regulation. Farm dairy effluent treatment is a relatively easy area for dairy farmers to improve environmental impact without having to change their current farming system. As farms become more intensive and the volume of effluent captured per cow and per farm increases it puts greater pressure on the current land application practice. Over time, farms are increasing the build-up of nutrients in soils and therefore reducing recycling efficiency of those nutrients.

1.4 Research Background

Currently there is a lot of social unrest regarding the state of the environment in New Zealand, and the treatment of it. This unrest is driving change in not only markets but also legislation. Consumers are increasingly demanding produce to be sourced using sustainable production techniques. This trend encompasses a wide range of markets not only agriculture. However, as agriculture relies so heavily on the environment for its productivity and profitability, the industry has an additional incentive to care for the environment. It is also a very vulnerable industry in that it is easy exposed to public opinion and critique.

The social unrest regarding the environment is a global phenomenon and is significantly influencing consumerism. As markets continue to move towards a demand for environmentally friendly products it is important that New Zealand dairying keeps up with those demands. New Zealand is known worldwide for its clean and green image. The dairy industry, being so reliant on its global market, is therefore reliant on the maintenance of this image. To maintain the ‘Clean and Green’ image of New Zealand it is important that we maintain high standards for environmental protection.

Waterways are an area that the agricultural industry is under pressure to reduce impact on. One way in which they could potentially reduce their impact would be improved handling of farm dairy effluent. Dairy farm effluent is high in nutrient content, biological oxygen demand and also contains other toxicants, such as endocrine disrupting hormones. Large volumes are produced (or captured) every day on dairy farms across New Zealand and world-wide. Enhancing the handling of this product and therefore reducing the potential for it to negatively impact the environment (and in particular the waterways), could have a significant benefit for the waterways of New Zealand.

1.5 Objectives

To identify and model a system that biologically treats FDE to produce a clearwater and treated solid effluent.

1.5.1 Research Question # 1

Using current technologies available in the wastewater industry can we create a system that improves the ability of the dairy industry to utilise the nutrients in the FDE and reduce the impact on the environment, alongside being practically and economically viable at farm scale?

1.5.2 Research Question # 2

How confident can we be in our model and comparisons?

1.5.3 Thesis Structure

The literature review researches the variables to be modelled and ways in which they may be treated/removed from FDE. This defines the systems that will be modelled and provides the data for the model. From the literature review a model was formed and then analysed. Discussion into the findings, limitations and future of this project.

Chapter 2. Literature Review

2.1 Introduction

The literature review examines the current and past literature relating; to the physical and chemical characteristics of farm dairy effluent (FDE) in New Zealand, effluent capture methods and pre-treatment of farm dairy effluent. Literature on the alternative methods of effluent treatment in other industries in New Zealand and will then be reviewed. This literature will include; anaerobic digesters, sequencing batch reactors and systems that include these methods of effluent treatment and will form a proposal for an alternative method of treatment. Parameters taken from this literature review will form a base for the data used to model the proposed treatment system. Finally, this literature review will discuss water quality standards and limits with reference to the legislation in which they are stipulated.

For the purpose of this literature review farm dairy effluent (FDE) can be defined as the untreated effluent collected during management of livestock, namely dairy cows, on a dairy farm. Where treated effluent is being discussed this will be noted. Treated FDE can be defined as FDE that has undergone a treatment or process that has altered its characteristics. FDE may be treated to varying levels depending on the process of the treatment.

2.2 Farm dairy effluent characteristics

The composition of dairy farm effluent can vary significantly depending on the system of the farm (System 1 -system 5). Differing systems can cause significant variation in the composition of FDE due to the composition of the FDE being related to the diet of the cattle. Variations in imported feed (maize silage, maize grain, Lucerne, oats and palm kernel are just a small number of common imported feeds used in New Zealand) also pasture composition throughout the year (for example; Lush pastures in spring and dry high dry matter pastures in summer) will also have an impact the composition of FDE.

Table 1: Nutrients in effluent from 100 cows under different scenarios (DairyNZ 2019).

Nutrients in the effluent from 100 cows under different scenarios

	Nutrients in effluent from 100 cows (kg/yr)			Effluent area needed to apply 150 kgN/ha*	
No feed pad – farm dairy effluent					
	N	P	K	% of farm	ha /100 cows
All grass system (milking 270 days, twice a day)	590	70	540	11	4
Feeding 2tDM/ha of maize silage in paddock	668	80	668	12	4.4
Using a feed pad – farm dairy effluent plus feed pad effluent (Feeding 2tDM/ha of maize silage)					
Time on the pad	N	P	K	% of farm	ha /100 cows
½ hour per day on pad	838	100	868	14	5.6
1 hour per day on pad	1008	120	1044	17	6.8
2 hours per day on pad	1348	160	1396	22	8.8
Feed comparisons (2 hours/day on pad)					
4tDM/ha/yr maize silage	1360	164	1460	25	8.8
4tDM/ha/yr grass silage	1588	184	1668	29	10.4

Table adapted from B. Longhurst, AgResearch 2004 – Adding Environmental and Economic Value to Dairy Effluent

*** Overseer should be used to determine effluent block size**

Nitrogen captured in FDE collected per year is 200 kg N/yr. less where 100 cows are fed 4 t DM/ha/yr. of maize silage compared with cows feed on grass silage was fed (DairyNZ 2019). Illustrating the impact of feed composition on FDE nutrient composition. New Zealand's pasture-based system means that throughout most of the year dairy cows are fed protein in excess to their requirement. Where protein is in excess, that protein (N) is excreted typically in urine. 50-60% of N intake (protein) is excreted in urine and a further 20-25% in faeces. Carbohydrates are a source of energy for microbial digestion (of protein) in the rumen. As carbohydrate content is increased and excess protein intake is lowered the percentage of N intake that is excreted is decreased. This is further evidence of the importance of feed content on excreta composition.

FDE contains dung and urine captured during periods of livestock management of dairy farms. These excreta are diluted at various rates depending on the wash down system of the farm. Scraping has the lowest level of dilution and hosing down has the highest level of dilution. This water input is generally a constant (or remains relatively the same within a system) however, rainwater makes the water additions to FDE variable as rainfall varies throughout the year. Detergents, chemical cleaners, antibiotics, milk, undigested feed and oils are examples of components of effluent from dairy sheds that remain relatively constant throughout the year.

Dairy cattle excrete about 54 litres (Vanderholm 1984) of urine and dung each day, of which approximately 5-15% is captured depending on the system. Vanderholm 1984, estimated that 8% of cattle excreta was captured each day (2hr ÷ 24hr = 8%, assuming the time average time spent in areas of collection is 2hrs (Vanderholm1984). However, the average New Zealand system has become more intensive since the time of Vanderholm’s study and therefore it is expected that the time cows spend on areas of collection (dairy shed, feed pads, standoff pads and cattle yards) has increased due to increased usage of feed pads and stand-off pads (herd homes or wintering pads).

FDE contains 86% wash water, 10% excreta (Longhurst, Roberts et al. 2000) and 4% teat washings and other foreign material (detergents, oils, milk, etc) on average. As mentioned previously this varies with the wash-down system. A dairy farm with a complete handheld hose wash down system will have a much higher wash-down water component than one with a feed pad that is scraped down.

2.3 Effluent capture

Effluent is captured during time of livestock management. This is typically twice a day at milking times. However, there are many other areas in which effluent is captured and as environmental awareness continues to increase the number of areas in which effluent is captured continues to increase.

- Dairy shed – typically effluent is captured twice a day during milking time throughout the milking season (approximately 300-315 days of the year).

Not all farms milk twice a day (some once a day, some on a 16-hour cycle) and some farms milk year-round.

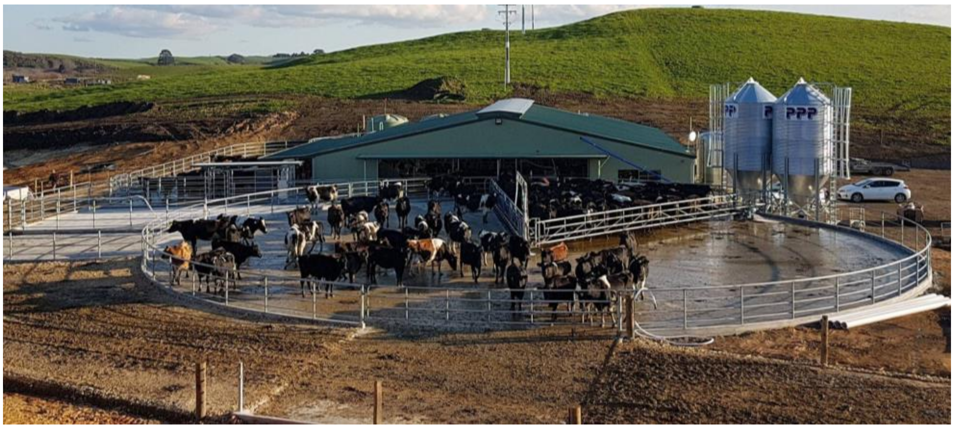

Figure 3: Photo of milking shed (taken from https://www.donchapmanwaikato.co.nz/)

Figure 4: Photo Credit: Waikato Dairy Builders (used with permission).

Figure 5: Photo Credit: Waikato Dairy Builders (used with permission).

- Feed pad – some dairy farms have feed pads where the cows are feed supplementary feed. This feed may be grown on farm and stored or purchased and is to better match feed supply with demand. Some farms feed year-round to enable a higher stocking rate.

Figure 6: Photo Credit: Waikato Dairy Builders (used with permission).

- Stand-off pad – can be concrete (rubber covered) or woodchip or sand. Used to stand cows off the paddocks in times of adverse weather conditions to stop or reduce paddock damage (pugging). These are typically used on farms with heavier soils where drainage doesn't occur as freely.
- Underpass – an underpass under a road, can be an area of effluent collection as it is an area where there is a high concentration of excreta deposition.
- Other areas may include; stock yards (if used frequently), herd homes (typically used in harsh climates where conditions have a negative impact on cow health) and any areas of concrete or tar-seal.

Another factor of effluent capture is the method of collection. Effluent can be collected using;

- Scraping

A hand or machine-driven (tractor) scraper is used to push excreta down to the collection area. This method is commonly used in conjunction with other methods, where both scraping and wash-down with a hand-held or flood wash are used. This is typically used on feed pads. Scraping alone does not achieve sufficient cleanliness levels for the cowshed yard.

Figure 7: Tractor effluent scraper (Rata Equipment, https://www.rataequipment.com/products/loader-attachments/yard-scrape).

Figure 8: (Right) Hand-held scraper (Farm source store, https://store.nzfarmsource.co.nz/catalog/supascraper-1-4m-regular/211295).

- A hand-held hose

A handheld hose uses clean water only, which has to be used to wash down the bails and any area within 5 meters of the last set of cups. Every cowshed therefore must have some variation of hand-held hose wash down.

Figure 9: Hand-held hose yard wash (DairyNZ, https://www.dairynz.co.nz/milking/track-and-yard/yard-and-handling-facilities/).

- Flood-wash

Flood wash typically uses recycled effluent liquid (after solids separation). Often a clean water option is also included. This is increasingly common for cowshed yards and is common for feed pads.

Figure 10: Flood wash on feed pad (taken from https://www.youtube.com/watch?v=qRbtdKL0_QU).

2.4 Pre-treatment of dairy farm effluent

2.4.1 Solid separation

Removing the solids changes the composition of the FDE being treated whilst also reducing the volume to be treated, it makes the effluent more manageable. Some effluent (especially that from areas where supplementary feeding occurs), has high levels of undigested feed; such as grain, maize, palm kernel expeller (PKE). These undigested products are difficult to remove in treatment systems and can lead to blockages or cause other problems, therefore removing them prior to treatment is important.

2.4.2 Gravity systems

Weeping-wall sludge stores are of the more commonly used methods of solids separation currently used on dairy farms across New Zealand. They are a large either concrete or pack earth (clay) pond where effluent enters one end and flows out through 6-10mm gaps in angled slats (DairyNZ 2012). The slats are angled such that any blockages from stones or the like are 'popped' bock into the sludge from the pressure. This reduces the likelihood of blockages. The solids remain in the weeping wall store and require removal. Weeping walls should be of a size such that removal is only required once a year. 40 m^3 storage is required for 100 cows per year. Weeping walls are a low cost (after capital), low maintenance and reliable method of solids removal (DairyNZ 2012).

2.4.3 Mechanical solids separation

Mechanical separation can achieve high rates of solids removal from both dairy shed and feed pad effluent. They have a higher capital cost than a weeping wall and are therefore more suited to larger scale operations (where 30-40 m^3 of effluent is produced per day).

Three main types of mechanical solids separations used in New Zealand Dairy are:

- Press separators – the effluent is forced through one or more fine layers of mesh screens to separate the solids and liquids. Liquids move through and the solids drop out. Screw press separators are normally built on raised platforms over concrete pads so that the solids can pile up below (DairyNZ 2012).
- Rotary de-waterers – effluent is pumped into a large rotating drum filer. The liquid drains through the drum filter and the solids fall out the end of the drum as it spins (DairyNZ 2012).
- Fixed screen separators – effluent is pumped over a specialised filter screen which allows liquids to drain through and solids are caught. The solids slide of the front of the screen and are collected in a bunker below (DairyNZ 2012).

2.5 Composition of farm dairy effluent

The nutrient composition, as stated in section 2.2, varies with the diet of the dairy herd. However, there are some industry accepted figures or 'standard industry figures' for the composition of farm dairy effluent in New Zealand. These figures are derived from Vanderholm 1984 and also those from the Dairying and the Environment Committee (DEC) (Vanderholm 1984, Heubeck, Nagels et al. 2014). It is important to note these standard figures used in New Zealand are much lower than those used internationally. This is most likely due to the differing systems, New Zealand being grass-based with smaller cows and different fed composition, and European and American farms having larger cows and a majorly mixed ration, with little to no grazing.

Table 2: Key industry guideline figures for cow shed effluent for FDE flow, Total Solids (TS), Total Nitrogen (TN) and Total Phosphorus (TP) by various authors, taken in part from (Heubeck, Nagels et al. 2014).

Source		**Vanderholm (1984)**	**DEC (2006)**
Average flow	(L/cow/day)	50	50
Flow range	(L/cow/day)	20-90	30-100
Average solids	(kg TS/cow/day)	0.36	0.55
Solids range	(kg TS/cow/day)	?-0.55	0.3-0.6
Average TN	(g TN/cow/day)	10.4	22.0*
TN range	(g TN/cow/day)	6.8-19.0	7.0-30.0*
Average TP	(g TN/cow/day)	1.76	2.5
TP range	(g TN/cow/day)	1.0-2.0	0.5-4.5

*TKN only, in fresh cowshed effluent TKN and TN very similar (Heubeck, Nagels et al. 2014).

Table 3: Characteristics of (fresh) farm dairy effluent taken from (Vanderholm 1984).

	Total		**Concentration**	
Parameter	**Average (kg/cow/day)**	**Range (kg/cow/day)**	**Average mg/L**	**Range mg/L**
BOD	0.08	0.04-0.10	1,500	1,000-4,500
COD	0.33	?-0.57	6,600	5,000-11,000
Total N	10.4	6.8-19.0	208	100-325
Total P	1.76	1.0-20	35.2	10-?
Total K	8.0	?-25		
pH range	8.0-8.5			

From Table 2 and Table 3 we can see that there are wide ranges of potential values. It is important to note that the Vanderholm (1984) may be outdated, as New Zealand dairying has progressed and developed greatly since 1984. The changes in the management of dairy farms may impact the compositions however these figures are recognised as industry standards. The standard figures given in Table 2 for DEC are higher than the Vanderholm data. This suggests that with the intensification of the dairy industry has come the concentration of farm dairy effluent. However, the differences are small and the ranges as shown are similar. The reference that Heubeck et al (2014) have used for the DEC is unable to be sourced and therefore the method to which that data was obtained could not be compared with the Vanderholm (1984). It is possible that the differences are due to variations in data collection methods. Due to being unable to source the original source of the DEC data the figures used in the remainder of this thesis and literature review will be those of Vanderholm (1984).

Longhurst et al (2000), found significant variation of mean N concentrations when the N content of 284 FDE samples were analysed. Mean concentration of the earlier studies noted by Longhurst et al (2000) were found to be between 181mg^{-1} and 223 mg^{-1}. This range is within that found by Vanderholm (1984) further validating those figures. However later (1990 and 1996) Taranaki and Waikato discovered mean N concentrations of 355 – 490 mg l^{-1} indicating the concentration of nitrogen in FDE are rising. This aligns with the aforementioned theory that with the intensification of the dairy industry the concentration of nutrients in FDE is increasing. Longhurst et al (2000) suggested that the increase in N in FDE could be due to increased N fertiliser use. This is because the period over which N in FDE increased also correlates with an increase in fertiliser use. Seasonal variation in N content of FDE is also present. The N concentration in FDE throughout the season curve follows the same approximate curve as pasture production throughout the season. Longhurst et at (2000) suggested that this may reflect the indigestible N content of the cow’s diet. This confirms that the diet of a cow directly influences the nutrient concentration of FDE.

Nitrogen is mainly in the form of organic N (urea and protein) in FDE, accounting for 80% (Longhurst, Roberts et al. 2000). Urine-N (which is mainly urea) volatilises rapidly as ammonia. Ammonium N accounts for 10-20% of total N and is the main inorganic N component of FDE (Longhurst, Roberts et al. 2000). Nitrate- N only accounts for a small portion. FDE therefore has a mixture of readily available and slowly available N which has supported land application of FDE in the past. As well as high levels of nitrogen, FDE has high levels of phosphorus and potassium.

The COD/BOD (chemical oxygen demand/biological oxygen demand) ratio of FDE is comparatively high (at 4:1) when compared to piggery waste-flushed (fresh) (at 2:1) (Vanderholm 1984). This is mostly due to the efficiency of the dairy cow's rumen at digesting food and its high fibre diet. This also leads there to be a lower fraction of biodegradable volatile solids than in other farm manures (Broughton 2009).

2.6 Current methods of handling/treating farm dairy effluent

2.6.1 Two pond Treatment

The two-pond treatment system was widely used as a method of treatment of FDE in New Zealand prior to the implication of the Resource Management Act (1991) (RMA). Since the implication of the RMA however, it has become increasing less common as it now requires a consent for use which is very difficult to obtain. The two-pond treatment system starts with a deep pond where anaerobic treatment occurs and then flows into a second much shallower pond where aerobic treatment occurs. Vanderholm (1984) found that 89.6% of BOD in the inflow FDE was removed in the anaerobic pond. A further 47.4% of the remaining BOD was found to be removed in the aerobic pond (Vanderholm 1984). Similar removal levels of COD were found in the anaerobic pond and aerobic ponds with 88.7% and 32.4% respectively. Nutrient removal was found by Vanderholm (1984) to be lower than the removal of BOD and COD. Nitrogen removal was found to be 20% and 55% for the anaerobic and aerobic ponds respectively. The removal rates of phosphorus in the anaerobic pond was 11.8% and in the aerobic pond was 25.8%. The two-pond system has been largely phased out due to this low rate of nutrient removal. The two-pond system no longer complies with the RMA (1991) and therefore requires a consent for use.

2.6.2 Land application

There are many variations of land application systems used throughout New Zealand. They are all based on the same principle, collect the effluent and spread it on the land. There are three main variations; sump and spray, holding pond and spray, and a system with solids separation and spray of liquid and separate discharge of solids.

Sump and spray is where the effluent is collected into a sump which holds typically no more than one day’s effluent. The effluent is then spread over land (the farms paddocks) using typically a travelling irrigator. This method has no treatment and relies on the land; soil, pasture and other vegetation, to filter, absorb and utilise the nutrients in the effluent (Waikato Regional Council n.d.). This system of handling effluent provides no treatment and can have severe environmental impact due to resulting overland flow and runoff (Houlbrooke, Monaghan et al. 2011). The high levels of nutrients, BOD and COD can have a negative effect on aquatic ecology. In severe cases this causes eutrophication, anoxic conditions and/or algal blooms (Smith, Tilman et al. 1999). The inflexibility of this system (due to only having a sump for FDE collection), means that the FDE must be applied to land as or immediately after collection regardless of the conditions. This increases the potential for runoff or overland flow to occur as effluent may be applied when soils are waterlogged or during heavy rainfall events. The use of a holding (storage) pond is not widely used to minimise the occurrence of such events (Houlbrooke, Monaghan et al. 2011).

A holding pond is used in conjunction with the sump and spray method. However, instead of pumping directly out of the sump for irrigation of FDE the FDE flows (not pumped if possible) down into a holding pond. The FDE is then pumped from the holding pond when conditions are suitable. The ponds act as a buffer for periods of poor conditions and as a contingency for breakdowns. This system is more widely used and accepted in dairying across New Zealand (Houlbrooke, Monaghan et al. 2011).

Application rates of FDE to land have a significant impact on the potential for negative environmental impact. Typical travelling irrigators apply FDE at a rate of 12-20 mm. The rate depends on the speed of the irrigator and therefore the size of the pump driving the irrigator. Small nozzle irrigation systems typically apply FDE between 6 to 12 mm. FDE can also be applied through irrigators or simultaneously with irrigation. Where FDE is put through irrigation pumps this can cause blockages resulting in reduced efficiency of water irrigations.

Solids separators; typically weeping walls, but also mechanical separators, are used to increase storage and handling opportunities. By removing the solid fraction, the liquid fraction is more easily applied to land. After separation the liquid is much easier to pump, therefore reducing pumping costs and if sufficient separation occurs (generally mechanical separation) small nozzle size irrigations systems can be used for the distribution of the liquid portion such as K-line or pivot irrigators (White and Hodgson 1999) (Kirk Irrigation n.d.). The ability to apply the liquid portion with a smaller nozzle size means that lower application rates can be achieved and therefore this increases the range of conditions suitable for the application of FDE. With solid separation not only does effluent become easier to apply but also the solids become easier to store. The nature and volume of the solids depends on the effectiveness of the separation system. The solids can be incorporated into the soil during cultivation of pastures or spread over the pasture using a muck spreader.

With all the variations of land application there is however the potential for mismanagement to cause environmental damage, due to the untreated nature of the effluent being applied to land (Houlbrooke, Monaghan et al. 2011)

Critical source areas such as mole and tile drainage cause the effect of soil infiltration to be mitigated. Mole and tile drains were used in earlier farming days (not as common now but are still around) to drain areas of land that would typically be too wet to graze. The mole and tile drains are designed to provide a direct route for water (and its contents) to leave the soil quickly. This is the opposite of the aim for applying farm dairy effluent to soil and can lead to direct losses of FDE into waterways.

2.6.3 Flocculation and Coagulation

Flocculation and coagulation separate the solid and liquid portions of the effluent by using and additive (flocculent or coagulant), that aids in binding the solids together making the particle sizes larger and therefore heavier increasing the rate of settling. The liquid portion of this is classified as green water so can only be used in the same ways the liquid portion of effluent can be when separated with other methods, such as mechanical separation (green water flood wash or irrigation). Solids can be used as described for other methods of solids separation. The benefits of using a coagulant and/or flocculent for solids separation stem from the fact that it is a form of treatment. The potential for negative environmental impact is therefore reduced with application of the products of these separation methods in comparison to raw FDE (Cameron and Di 2019). Flocculation and coagulation are new technologies to the New Zealand Dairy industry and are only beginning to be commercialised.

ClearTech is the product name of a flocculant technology being promoted through Ravensdown, developed by Lincoln University and Ravensdown (Cameron and Di 2019). ClearTech uses polyferric sulphate (PFS) as a flocculant. Large tank trials have been found to successfully reduce the turbidity by 99%, as well as a 99% reduction in *Escherichia coli*, 57% reduction in nitrogen and 99% reduction in phosphorus. A sequencing batch reactor pilot plant was found to effectively treat 17,000 L (to the standards previously stated) between milking’s. The batch cycle was a based on the turbidity of the influent. A turbidity probe relayed data to a PLC which was used to calculate and dose the FDE with the correct amount of PFS solution to treat the FDE. The FDE was then stirred for 15 minutes and allowed to settle for 30 minutes. If the top 200mm depth of the FDE had not reached the required 100 NTU in 15 minutes then more PFS was added. The cycle repeated until the pre-set turbidity measure was met. The FDE was then left to settle for 4 hrs. After four hours the clarified water was pumped off the top using a pump mounted on a floating pontoon, the pontoon had a turbidity meter underneath and as the clarified water was pumped out the pontoon lowered, until the turbidity meter detected a rise in turbidity (above 100 NTU) which triggered the pump to stop. The recycled water valve was closed and the effluent storage pond valve opened and the treated effluent was pumped out (Cameron and Di 2019).

2.7 Current and proposed legislation

2.7.1 The Resource Management Act 1991

The overarching piece of legislation that governs the handling of FDE in New Zealand is the RMA (1991).

The RMA (1991) states in section 15.1 “no person may discharge any –

(a) Contaminant or water into water; or
(b) Contaminant onto or into land in circumstances which may result in that contaminant (or any other contaminant emanating as a result of natural processes from that contaminant) entering water; or…

unless the discharge is expressly allowed by a national environmental standard or other regulations, a rule in a regional plan as well as a rule in a proposed regional plan for the same region (if there is one), or a resource consent.” (New Zealand Government 1991).

Within this piece of legislation, regional councils are required to provide a plan which lays out objectives and policies to implement those objects and rules if needed to enforce those policies. These plans must give effect to any; national policy statements, national coastal policy statements, national planning standards and any regional policy statements. The regional plan must record how a regional council has allocated a natural resource, if one has been allocated (New Zealand Government 1991). Many regional councils are still going through the process of agreeing and legalising their regional plans. These regional plans (established and proposed) are introducing regulation on dairy farming practices to ensure the upkeep of New Zealand’s green clean image. Environment Canterbury’s ‘Canterbury Land and Water Regional Plan (LWRP)’ has been in play since 2015 and is based on an integrated approach to managing land and water resources together. Since its implementation there have been a many plan changes or updates, which are generally district specific.

Horizons Regional Council’s ‘One Plan’ has also been implemented for some time now, since 2014, and has also had some changes since it was implemented. Both plans have taken an integrated approach to land and water management. Horizons council have also integrated air quality management into their ‘One Plan’ where Environment Canterbury has this separate. Horizons ‘One Plan’ lays out specific conditions where a consent to farm and a consent to discharge are required (Appendix 1 - Horizons Regional Council - One Plan) (Horizons Regional Council 2014). In contrast to Horizon's Regional Council's approach, Environment Canterbury's approach has led to the majority of Canterbury dairy farms requiring a land-use consent to farm. Unless covered by and irrigation scheme or collective; all farms greater than 10ha or with land within a 'red – zone' must have a land-use consent to farm. This generally requires a Farm Environmental Plan (FEP) and a nutrient budget. Audits are required for farms that have a land use consent or are part of an irrigation scheme or collective (DairyNZ n.d.).

The land-use consents previously mentioned are typically based around a nutrient budget and environmental plan and within these two pieces it is often required that farms work to 'reduce' N leaching or move towards a set limit. The environmental plan, nutrient budget and leaching limits are all impacted by effluent handling. This has brought about a new drive from farmers for more efficient systems, surpassing their current legal requirement, as this is a way for farmers to perform better environmentally without impacting their productivity.

2.8 Alternative methods of effluent treatment outside of the agriculture industry

2.8.1 Wastewater treatment plant (sewage)

There are many steps to wastewater treatment, each step has a range of options which all must be optimised to form a system to suit the inflow wastewater, the volume and the desired treatment. The basic steps are;

- Collection
- Preliminary Treatment (Screening and filtration)
- Primary sedimentation
- Active Treatment
- Disinfection
- Discharge

Collection systems of wastewater are not relevant to the current literature as this infrastructure will most likely be already in place.

1.1.1.1 Preliminary treatment

Preliminary treatment or pre-treatment is the first attempt at removing waste solids. It is generally conducted in a series of steps each removing smaller sized material. Screening is the initial step; this is typically a screen in which bars equidistance apart collect larger material as the waste water moves through. Manual or mechanical cleaning of these is required to ensure build-up does not block flow. Screening removes items such as household waste, sticks, leaves, rags etc. Factors to consider when determining screening use are, plant design, solids load, and whether or not screening should be constant, intermittent or for use only in emergencies (Drinan and Spellman 2012).

Shredding is an alternative to screening or can be used as well as screening. It approaches the problem of large solids in a different way to screening. Instead of removing larger solids, shredding makes larger solids smaller. This enables all the waste to be treated together. Comminution is the preferred method and is where the wastewater enters a grinder assembly, objects too large are pushed aside and must be manually removed. The grinder assembly includes; 2 cutters, one either rotating or oscillating and one fixed and a screen or slotted basket. Once the solids have been shredded, they pass through the screen and to the next stage of the plant. Barminution combines shredding and screening and is where the solids collected on the bar screen are shredded post collection and then combined back into the wastewater. With shredding, it is important that the cutter is correctly aligned and sharp so regular maintenance and replacement is important(Drinan and Spellman 2012).

Grit removal occurs after screening or shredding. Wastewater may contain gritty materials such as eggshells, sand, silt, which can cause excessive wear on pumps and other equipment. There are many ways to remove grit but the three main forms of removal are, gravity/velocity, aeration and cyclone (or centrifugal force). Gravity/velocity occurs in a channel where the velocity of the water is maintained at the optimum 1 ft per second (0.3048 m/s) such that grit settles but organic matter does not. The velocity is controlled by the amount of water flowing through the channel of a known width and depth. Removal of settled grit can be mechanical or manual (Drinan and Spellman 2012).

Aeration grit removal is where aeration is used to suspend inorganic matter but not grit. The balance of aeration must be optimised such that grit settles and everything else is suspended. Too much aeration and the grit is also suspended, not enough aeration and the inorganic solids also settle. Typically, aerated grit removal systems are mechanically cleaned. Cyclone grit removal is where centrifugal force is used to separate heavier grit particles from the lighter organic matter. This method is not typically used in the entire wastewater stream, it is more often used on primary sludge (Drinan and Spellman 2012).

1.1.1.2 PRIMARY SEDIMENTATION

Primary sedimentation typically occurs after the pre-treatment and before the active treatment. Primary treatment occurs in rectangle or circular tanks in which the heavier solids settle to the bottom to form primary sludge. The oils, fats, grease and other floating material forms a scum on the surface which is skimmed off. The efficiency of this process is controlled by detention time, temperature, tank design and equipment condition.

1.1.1.3 ACTIVE TREATMENT

Biological treatment and chemical treatment

Biological treatment processes fall into one of two categories. Fixed film systems (trickling filter beds and rotating biological contactors) and suspended growth systems (activated sludge processes).

Currently the most widely-used biological treatment of municipal wastewater is activated sludge. The activated sludge system recirculates part of the “sludge” or biomass (Drinan and Spellman 2012). It removes biological oxygen demand (BOD) and suspended matter through aerobic decomposition. There are two steps in the activated sludge process. Step 1 the aeration tank where new sludge is mixed with recirculated ‘activated’ biomass. Air or oxygen is pumped into this tank to maintain aerobic conditions. Whilst agitation occurs to ensure thorough mixing of the two inputs. The mixed wastewater then flows into a secondary tank or settling tank. In the settling tank the solids (mostly biomass) settle to the bottom. A portion of the settled solids are the recirculated sludge. The recirculation of sludge provides reduced period for the adaption of microorganisms to the change in composition of wastewater. There are many factors that affect the efficiency of an activated sludge system; temperature, pH, organic matter content, oxygen availability, aeration time, and wastewater toxicity. However, the most important factor (and most common cause of failure) is ensuring the balance of organic matter (input wastewater), activated sludge (microorganisms) and oxygen (DO) (Drinan and Spellman 2012).

Trickling filter systems are designed to remove biological oxygen demand and suspended solids. The wastewater is moved over a media such that it comes into contact with the microorganisms attached (or fixed) to the filter media. The filter media may be fist-sized stone, redwood, plastic or any substance capable of withstanding weather conditions for many years. The wastewater is dispersed over the top of the media and forms a thin layer as is moves down through the filter at intervals. The intervals enable oxygen to come into contact with the microorganism’s in-between wastewater applications. This promotes the aerobic decomposition of the solids by the organism which in turn leaves a more stable waste and an increased population of microorganisms (Drinan and Spellman 2012).

Rotating biological contactors (RCBs) is an alternative method of effectively the same process as the trickling filter bed system. An RCB has a number of (3.5m diameter) disks mounted on a horizontal rotating shaft such that 40% of the disk is submerged at any one time. The shaft rotates slowly to provide a similar situation as the trickling filter bed of, wastewater contact then air contact. The biomass film on both the discs in an RCB and the filter media in a trickling filter bed is called zoogloeal slime. In both systems any excess solids and waste products, slip off the media as sloughing. The sloughing’s are removed in the settling tank (the next stage of the process) (Drinan and Spellman 2012).

After all these biological treatment methods there must be secondary sedimentation to remove the accumulated biomass.

1.1.1.4 Secondary Sedimentation

Secondary sedimentation is essential for all of the biological treatment processes previously detailed. Secondary settlement ensures maximum removal of suspended solids by providing an environment in which gravity settling can occur. It is essential the unsettled sludge is removed at this stage to ensure it does not enter the receiving water body. In the secondary settling tank is it important to monitor the flow pattern to ensure uniform distribution as well as turbidity to ensure that all (effective) suspended solids have been removed (Drinan and Spellman 2012).

Chemical wastewater treatment processes include; chemical precipitation, ion exchange, neutralisation, adsorption and disinfection. Chemical wastewater treatment can result in the pollution of the portion of the wastewater that reacts with the chemicals (the solids) (Samer 2015). As well as this, a portion of the pollutant (reactant) will remain unaffected. The high cost of the chemical additives combined with the environmental problem of disposing of high levels of ‘chemical’ sludge makes chemical treatment unviable. However, chemical treatment is often used after biological treatment to remove toxic compounds such as viruses (Samer 2015).

Chemical precipitation is also known as coagulation/flocculation. It is where the wastewater is dosed with a chemical coagulant which stimulates the joining of particles to form larger heavier particles. The now larger particles then settle to the bottom more easily (Samer 2015).

Adsorption is a physical process where soluble molecules are removed by attachment to the surface of a solid substrate. A commonly used example of this is activated carbon filtration. The adsorbent should have an extremely high specific surface area and should be activated prior to being used (free of adsorbate) (Samer 2015).

Disinfection is the final step of tertiary treatment. Disinfection is a chemical process in which pathogens are killed or at least inactivated. The ideal disinfectant should have bacterial toxicity, is inexpensive, not too dangerous to handle and should have a reliable means of detecting residuals. Chlorine and ozone are chemical disinfection agents while ultraviolet disinfection (UV) uses high intensity light to disrupt bacterial DNA and prevent bacteria from reproducing (Samer 2015).

The waste-water treatment systems described in this section are typically optimised for municipal waste treatment or sewage waste. This waste has been subject to much harsher regulation in terms of discharge in recent years, due to the vast scale of effluent being processed. By utilising this already existing technology and altering it to optimise it for the variation in composition and inflow rates would potentially enable dairy farmers to meet the challenging new regulations.

2.9 Other Technology available

2.9.1 ATU's – Aerobic treatment units

The unit process used for aerobic treatment units (ATU) technology used is based in well-established technology already used in centralised large-scale wastewater treatment plants. The new technology is in the design and packaging of the systems that enables essentially a mini wastewater treatment plant to be installed on farm and home properties. To enable this, the systems have to be easy to use (require low levels of attention) dependable and low maintenance. Concepts from this technology may be applicable for dairy farm effluent treatment systems in the future.

Typical ATUs operate as intermittent-flow, complete mix tank, constant volume reactors. The rate of inflow is intermittent as it is not continuous. The contents of the aeration chamber are well mixed to ensure maximum contact with dissolved oxygen, microbes and wastewater. The effluent moves out of the aeration chamber and into a clarifier and the rate of discharge is directly related to the rate of inflow. The exception to this is sequencing batch reactors. Which are discussed further below. Of the ATU technology, the two of interest here are the suspended growth bioreactors which act as previous described and the sequencing batch reactors (Jantrania and Gross 2006).

1.1.1.5 Suspended growth bioreactors

Process

Primary treatment is provided by a 'trash tank' or an initial tank where detention time is shorter (smaller tank). The main septic tank is aerated. Aerobic microbes convert organic compounds into energy, new cells and residual matter. As water moves through the clarifier, a portion of the biosolids are retained within the ATU. These retained solids act as a seed for new microbial growth. Settled biomass and residuals accumulate in the bottom and require periodic removal (Jantrania and Gross 2006).

Suspended growth bioreactors Design

The ATU is designed as a scaled down activated sludge plant. The cone shape of the clarifier works to separate the solids out. As the cross-sectional area of up flow increases the fluid velocity decreases. Once the settling velocity biomass is greater than the fluid velocity then the biomass will no longer move upwards and it will settle back into the aeration chamber during periods of no flow.

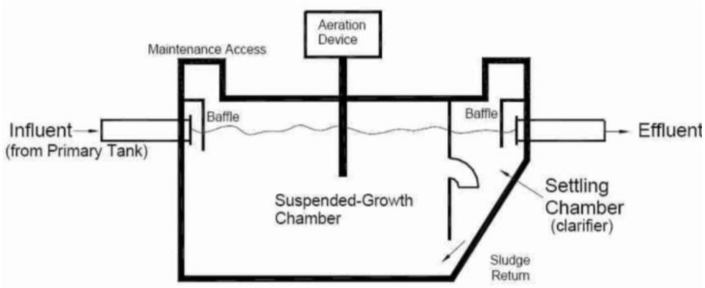

Figure 11: Diagram showing ATU design (taken from https://inspectapedia.com/septic/Aerobic1DF.jpg).

1.1.1.6 Sequencing batch reactors

A sequencing batch reactor (SBR) is a fill and draw activated sludge system for wastewater treatment. An SBR is essentially a system in which the microbial decomposition of suspended solids and solid settlement occur in the same tank in a fill and draw cycle. One cycle has 5 basic modes. fill, react, settle, draw (also called decanting) and idle. First the tank fills (aeration is cycled on and off during this phase), then aeration is continued to be cycled on and off during the reaction phases to promote the oxidation of organic matter and also denitrification. Aeration is shut off next to allow the wastewater to become anoxic and also to provide conditions for very effective solid liquid separation. During this phase denitrification occurs. Following clarification, the clarified supernatant is removed, this occurs using adjustable weirs, floating weirs or submersible pumps. As with the suspended growth bioreactor excess biosolids must be periodically removed. The idle phase is the time between cycles. Two reactors may be used to maintain continuous inflow (Tilche, Bacilieri et al. 1999).

The anaerobic and aerobic cycle of an SBR can be optimised such that nitrogen and phosphorus removal is maximised. Simultaneous nitrification and denitrification can occur at low DO (dissolved oxygen) levels. It has been found that the cyclical aerations when operated with the correct combination of high and low dissolved oxygen levels can produce increased removal of nitrogen and phosphorus as well as increased sludge settling. The cyclical nature increases the population of polyphosphate-accumulating organisms thereby increasing the removal of phosphorus (Jantrania and Gross 2006).

2.10 Enhanced Biological Nutrient Removal Sequencing Batch Reactor

Biological nutrient removal is a secondary wastewater treatment process in which microbial activity removes the nitrogen and phosphorus from the wastewater. These micro-organisms are typically present in the wastewater but a seed population (activated sludge) is typically retained (once the process is started up), which has a higher proportion of the active micro-organisms required for enhanced biological nutrient removal or EBNR. This process involves a cycle of anaerobic, anoxic and aerobic phases for the removal of both nitrogen and phosphorus.

Some processes focus primarily on the removal of either nitrogen or phosphorus as the removal of each is a different process, but they can be run simultaneously with suitable efficiency.

Biological phosphorus removal is a process in which phosphorus-accumulating organisms (PAOs) store phosphate as intracellular polyphosphate, this leads to the removal of P from the bulk of the liquid. PAOs take up carbon sources such as volatile fatty acids, (VFAs) under anaerobic conditions. These VFAs are stored intracellularly as carbon polymers (poly-β-hydroxyalkanoates, PHAs). The energy for this is generated from the release of phosphate from the cell due to the splitting of polyphosphate. Under aerobic conditions, PAOs use there stored PHA as an energy source for growth, glycogen replenishment, P uptake and polyphosphate storage (Oehmen, Lemos et al. 2007, Akbarzadeh, Khodabakhshi et al. 2012).

Biological nutrient removal (BNR) from wastewaters is achieved through removal of activated sludge which contains a high level of polyphosphate. While this process is typically achieved through anaerobic and aerobic cycling, the use of anaerobic, anoxic cycling is an alternative. Some PAOs are able to use nitrate or nitrite for anaerobic respiration and therefore undertake both phosphorus uptake and denitrification simultaneously. This is the basis of biological nutrient removal, where the process is optimised for the efficient removal of both nitrogen and phosphorus(Oehmen, Lemos et al. 2007).

Biological removal of nitrogen occurs in a two-step process, firstly nitrification, where ammonia is converted in to nitrate, the second is denitrification where the nitrate (or nitrite in some cases) is converted to nitrous oxide (N_2O) or nitrogen gas (N_2). Nitrification occurs under aerobic conditions and denitrification occurs in anoxic conditions. Instead of carrying out these two stages in separate tanks a sequencing batch reactor is used. This means that a sludge return network is not required, aerators are required to cycle on and off providing aerobic and anaerobic phases.

To provide sufficient removal of both phosphorus and nitrogen there are many different systems of SBR operation including; SBRs with; 5 phases; fill/aerobic, anaerobic, settle decant idle, to SBRs with seven; fill anoxic, anaerobic, aerobic, anoxic, aerobic, settle, decant, idle. In a study carried out by Keller et al (Keller, Watts et al. 2001), it was found that by using a simultaneous fill and decant cycle, the challenge of efficiently utilising chemical oxygen demand was mitigated. In this study fill occurred from the bottom of the tank under the sludge blanket whilst decanting was occurring. This method is a patented process termed UniFed (Keller, Watts et al. 2001) and would have the added benefit of improving time efficiency due to no idle phase and simultaneous fill and decant phases. The design of the tank would however have to be optimised for such operation system.

Similar to this is the operation system studied by Albarzadeh et al (Akbarzadeh, Khodabakhshi et al. 2012), where fill is anaerobic followed by an anoxic phase. This is a similar system in theory as it is ensuring the optimisation of the phosphorus removal by beginning with an anoxic phase to enable VFA uptake and initial denitrification. This enables the aerobic phase to be most efficient, in that both the removal of phosphorus by PAOs and also nitrification by nitrifying bacteria (Michael H 2002, Akbarzadeh, Khodabakhshi et al. 2012).

2.11 Anaerobic Digestion

Anaerobic digestion is the process or collection of processes in which microorganism's breakdown biodegradable material in an oxygen free environment. There are four stages of anaerobic digestion; hydrolysis (hydrolytic bacteria), acidogenesis (acidogenic), acetogenesis (acetogenic hydrogenating and dehydrogenating bacteria) and methanogenesis (by hydrogenotrophic and acetoclastic bacteria) (Tie and Sivakumar 2006).

The main utilisation of anaerobic digestion technology with dairy manure is for the production of energy. The process of anaerobic digestion of dairy manure produces biogas which typically contains 60% methane and 40% carbon dioxide (Wilkie 2005). Water vapour and trace amounts of hydrogen sulphide are also present. The process of anaerobic digestion of dairy manure and its development have been driven towards the maximisation of methane production to maximise the energy production. However, the benefits for a dairy farm system extend beyond energy production; weed seed inactivation, nutrient conservation and mineralisation, odour control and improved social acceptance ('green' image) are a few of the main benefits.

There are many designs for anaerobic digesters; the basic requirements of a digester are an oxygen free environment which allows for continuously high sustainable organic load rate and a short hydraulic retention time to maximise efficiency and minimise reactor volume. Size and shape is an important consideration, square or rectangular reactors may be easier to build but provide difficulties for mixing. Anaerobic digesters can have various levels of mixing from very little, to continuously stirred. A certain degree of mixing is required to ensure contact of the bacteria with the influent (Ward, Hobbs et al. 2008).

Anaerobic digesters can be one stage or two stage, common designs for one stage reactors used for the digestion of dairy effluent are; covered lagoon, complete mix, plug-flow. Covered lagoon is where a gas-tight cover is fitted over a lagoon/pond to capture the biogas. This could potentially be retrofitted to existing storage ponds. Hydraulic retention times (HRT) vary from 35 days to 60 days (Wilkie 2005).

Complete mix digesters or continuously stirred tank reactors (CSTR) are systems where the digestants are intermittently mixed by mechanical agitation, effluent recirculation or biogas recirculation. Despite the name these systems are typically intermittently stirred. HRT varies from 20 – 25 days (Wilkie 2005).

Plug flow digesters are unmixed systems where the material flows semi-continuously as a plug through a horizontal reactor. The hydraulic retention time is 23 – 30 days (Wilkie 2005).

Fixed film digestion is where bacteria is immobilised on a media (fixed film) within the digester, preventing the wash out of microbes and providing a distribution of microbial biomass throughout the reactor. The HRT is typically 2 - 4 days (Wilkie 2005).

2.12 Sand Filter

A sand filter generally consists of a number of layers of differing size sand particles ranging from very fine to gravel with the fine sand at the top and the gravel at the bottom. Depending on the type of sand filter, the solution (partially treated waste water) is fed onto the surface or into the top layer of the sand filter. In the case of gravity discharge, the bottom of the sand filter must be above the collection point. Pumped discharge sand filters have no restrictions in terms of elevation in relation to the collection point as the discharge is pumped out. Both of these types of sand filter are contained. The final type of sand filter is a bottomless sand filter where the sand filter is not lined and rather than collect the discharge it is discharged directly to the soil below. The efficiency of a sand filter depends largely on its construction however, they have been shown to achieve high levels of removal, such as 98% removal of BOD, 90% potassium and 40% of total nitrogen (United States Environmental Protection Agency 1999). These removal rates were from anaerobically treated septic tank effluent. The benefits of sand filters are that they are low cost for both construction and running, they are easy to manage and effective. However, it is important to ensure design is correct for the system in operation and the size is correct. This coupled with regular maintenance mitigates the issue of blockages (United States Environmental Protection Agency 1999).

2.13 UV Disinfection

Ultraviolet disinfection is where Ultraviolet (UV) lamps, emit light in the range of 200 – 400 nm wavelength. The 200-300 wavelength light is absorbed by the DNA and RNA of microorganisms and causes changes to the structure of the DNA and RNA rendering the organisms incapable or replication. This inability to replicate stops them from being able to cause disease, even though they are still alive metabolically. UV disinfection is a physical process with no chemicals added, therefore there is no residual in the water after the water leaves the UV reactor. UV disinfection is commonly used for treatment of drinking water and can be the final stage of treatment.

Disinfection to the same levels can be achieved through chemical treatment such as chlorination, however chlorination leaves a residual effect in the water. This is therefore not a practical method for use in dairy farm systems due to the adverse environmental impacts of residual chlorine.

UV disinfection efficiency depends directly on the design and depends on the target pathogen. If the target is cryptosporidium and giardia, then a much lower dose is required than if it was viruses (Staff and Cotton 2008).

2.14 Water Quality Standards and Limits

The quality of treated water determines its potential use. ClearTech liquid effluent is deemed green water and therefore may not be used through a handheld hose. Permitted use of green water is for flood wash only and not within 5m of the milking parlour. Solid separated liquid effluent is also deemed greenwash and therefore in terms of recycling ability ClearTech brings no advantage. So, in order to increase recycling ability over currently available technology any proposed system must improve the quality of the water to a higher standard than ClearTech. The limiting factor for ClearTech is *E. coli* concentration in the effluent is too high, so for recycling ability or in order to use the water in shed and through a hand-held hose *E Coli* concentration needs to be reduced to a level that is acceptable for human contact. There are currently no set limits or parameters for what is acceptable and what is defined as green water. The definition of a substance as green water and clear water is currently determined by consent. In order to make a reasonable assumption on the expected standards of water quality required to deem a discharge effluent as clear water, and/or to enable discharge of treated effluent into waterways, an investigation into various water quality standards and WWTP discharge effluent quality has been undertaken. To ensure that the standards are not overestimated the lowest required value for each parameter will be used as a baseline to compare the performance of the EBNR ABR/SBR system.

There are a number of parameters that are used to determine the quality of water. A small number of parameters have been identified as key to assessing the treatment of farm dairy effluent, the resulting treated effluent and its potential environmental impact if discharge directly into a waterway. These parameters are; total nitrogen (TN), total phosphorus (TP), biological oxygen demand, total solids (TS), and *Escherichia coli* (*E. coli*, EC).

Horizons regional council have broken down their Water Quality standards into catchments and sub-catchments. The following table (Table 4) is a summary of the figures used to guide the council. From these tables we can see widely accepted values for a number of water quality parameters (Ausseil and Clark 2007).

Table 4: Summary of relevant recommended water quality standards for the protection of different waterbody values. Modified from Ausseil and Clark 2007, Table 21.

Value	Parameter	Standard	River Flow	Time of the year
Life-Supporting Capacity Lake waters	TP	20 mg/m^3 (annual average)	N/A	Year round
	TN	337 mg/m^3 (annual average)		
Contact Recreation and Aesthetics	*Escherichia coli*	260 /100 ml	median	1 November to 30 April
		550 /100 ml	< 3 x median	Year round
Life-Supporting Capacity UHS/UVA, TF (Trout Fisheries) Class II – Regionally significant and TF (Trout Fisheries) Class I - Outstanding	BOD_5	1 g/m^3	All	Year round
	POM	2.5 g/m^3		
Life-Supporting Capacity UVM/Uli	BOD_5	1 g/m^3	All	Year round
	POM	5 g/m^3		

Table 5 cont.: Summary of relevant recommended water quality standards for the protection of different waterbody values. Modified from Ausseil and Clark 2007, Table 21.

Value	Parameter	Standard	River Flow	Time of the year
Life-Supporting Capacity HM/HSS/LM/LS and TF (Trout Fisheries) Class III Other significant fisheries	BOD_5	2 g/m^3	All	Year round
	POM	5 g/m^3		
Stock water	Faecal *coli*forms	400 /100 ml	All	Year round

Table 6: Water Quality Standards - Horizons District Council, taken from Ausseil and Clark 2007, Table 26.

Parameter	Limit	Notes
TN	<337 mg/m^3	
TP	<20 mg/m^3	
BOD_5	<2 g/m^3	
POM	<5 g/m^3	
Escherichia coli	<260 /100 ml	during the period 1st November to 30th April inclusive
	<550 /100 ml	Year round

The national policy statement for freshwater management (NPSFM) amended 2017 sets out limits for total nitrogen, total phosphorus and *E. coli.* These limits differ slightly from those set out by the Horizons Regional Council, especially in terms of phosphorus. The limit for total phosphorus set in the NPSFM is half of that specified by Horizons Regional council at $\leq$ 10 mg/m^3. A draft NPSFM was released in September 2019 to replace the National Policy Statement for Freshwater Management 2014 (as amended 2017). The limits set by the draft

NPSFM have remained the same for the three relevant parameters. Table 6 details those limits set by both the old and draft NPSFM.

Table 7: TN, TP and *E. Coli* attribute band A limits, taken from Draft National Policy Statement for Freshwater Management, September 2019: Appendix 2A, Tables 3, 4 and 11(New Zealand Government 2019 2019).

Parameter	Limit	Value (and component)	Notes
Total N	≤ 160 mg/m^3 or ≤ 300 mg/m^3	Ecosystem Health (water quality)	Annual Median for lakes Seasonally Stratified and Brackish or Polymictic
Total P	≤ 10 mg/m^3	Ecosystem Health (water quality)	Annual Median for lakes
Escherichia coli	Exceedances over 540 cfu /100 ml <5% Exceedances over 260 cfu /100 ml <20%	Human contact (human health)	For at least half of the time the estimated risk is < 1 in 1000 ml (0.1% risk)

As well as current limits and recommended limits, information regarding the current performance of waste water treatment plants have been assessed. The performance of waste water treatment plants is important as they are the basis for the EBNR ABR/SBR system has been based and they already have been granted consent to operate. If the EBNR ABR/SBR system operates at to a similar level of performance as currently consented WWPT's that discharge to water, this may be sufficient for use in dairy farm systems.

Table 8: Summary Statistics for Pahiatua WWTP Discharge (years 2008-13), taken from OPUS International Consultants Ltd, Pahiatua WWTP Discharge of Treated Wastewater; Appendix 6.3 (Manderson 2014).

	No. of cases	Min	Max	Median	Mean	SD	Year
E. Coli	12	594	260,250	4362.5	74,188.2	100,568	2008
TN		7.95	28.3	14.95	15.5	5.9	
TP		2.69	7	4.225	4.7	1.6	
$CBOD_5$		0.5	5	2.25	2.3	1.5	
TSS		13	140	71.5	78.7	38.1	
E. Coli	12	472	461,110	146,440	16,0164	159,535	2009
TN		3.15	31	22.45	21	7.1	
TP		0.29	6.79	4.495	4.4	1.7	
$CBOD_5$		0.5	3	1.75	2.1	0.9	
TSS		6	115	71	67.8	36.1	
E. Coli	12	0.5	2,142	308	611.3	697.9	2010
TN		3.9	20.5	9.68	10.8	6.1	
TP		0.15	4.75	2.815	2.5	1.8	
$CBOD_5$			4.3	2.9	2.4	1.2	
TSS		0.5	110	22	42.3	43.1	
E. Coli	12	0.5	5,300	2	659.6	1,560	2011
TN		2.4	22	4.45	6.9	5.9	
TP		0.13	4	0.174	1	1.6	
$CBOD_5$		0.25	1.5	0.75	0.8	0.4	
TSS		0.5	124	6	16.1	34.2	

Table 9 cont.: Summary Statistics for Pahiatua WWTP Discharge (years 2008-13), taken from OPUS International Consultants Ltd, Pahiatua WWTP Discharge of Treated Wastewater; Appendix 6.3 (Manderson 2014)

	Number of cases	Min	Max	Median	Mean	Standard Deviation	Year
E. Coli	12	0.5	1,200	51	245.4	399	2012
TN		2.9	26	4.8825	8	6.8	
TP		0.12	3.227	0.315	1.1	1.3	
$CBOD_5$		0.25	2	0.485	0.7	0.6	
TSS			19	4.5	6.1	5.5	
E. Coli	12		105	0	13.3	30.3	2013
TN		3.384	4.86	3.945	4.1	0.4	
TP		0.046	0.123	0.1075	0.1		
$CBOD_5$		1	3	1	1.3	0.6	
TSS			5	1	1.2	1.6	

From Table 8 for Pahiatua WWTP, overall maximum discharge for; *E. coli* was 461,110 cfu /100 ml, total nitrogen was 31 mg/L, total phosphorus was 7 mg/L, biological oxygen demand was 5 mg/L and total suspended solids was 140 mg/L. However, over the study period there was a notable improvement in quality of effluent discharge. *E. Coli* was found to exceed the Horizons Region Council target less than 20% of the time since 2011 and in 2013 (the final year of the study) less than 5% of the time. Levels of *E. Coli* have been noted since 2012 to be such that wastewater discharge may actually improve the water quality of the receiving environment due to dilution of faecal *coli*forms present upstream in the receiving waterway.

Although maximum levels have been significantly higher, improvements have been made to the plant and current (as at 2013) performance has increased in some cases more than 10-fold. Coupled with increasing pressure to improve it is unlikely that consents will be approved at the level of performance shown by these results. The performance of Pahiatua waste water treatment plant in 2013 was the closest overall to discharge equalling the standards set by Horizons for their water quality targets. However, neither total P or total N meet those targets. The impact of a discharge effluent on an environment is largely impacted by the dilution factor (or flow of receiving environment). If the discharge point is into a large fast flowing river the impact is likely to be less than into a slow flowing and/or smaller river as there will be less dilution. This is why the Pahiatua WWTP is likely consented to discharge at levels higher than the water quality standards set by Horizons and the National Policy Statement for Freshwater Management.

2.14.1 Efficiency of treatment systems

There is a wide- ranging variation in the efficiency of treatment systems and defining how efficient a system is at treatment is difficult. Jantrania and Gross have defined a scale in the book 'Advanced Onsite Wastewater Systems Technologies'. The overall treatment level (OTL) is based on the removal level of each of the constituents of interest. The general calculation provided is designed to be able to be altered to meet specific requirements. The OTL of a system is defined by the weighted average of the removal rates of the constituents of interest (Jantrania and Gross 2006). A variation of this system could be useful for the comparison of effluent systems for dairy farmers and regulatory bodies across New Zealand.

Chapter 3. Modelling

3.1 Introduction

The new system modelled utilising enhanced biological phosphorus removal and nitrifying denitrifying anaerobic digestion and sequencing batch reactor technology will from this point on be referred to as BioClean.

Firstly, the treatment systems to be modelled were; Two pond treatment, Land Application, ClearTech and BioClean. Variations include; number of cows, wash down method (hand held hose, flood wash, and scraped), soil drainage (well drained or poorly drained) for land application, solids separation method (weeping wall, fixed screen separation or screw press separation), and the feed system used on farm. Feed variations include differing feed composition (completely grass or a combination of grass and maize silage), and differing use of a feed pad (from zero to four hours on feed pad). Length of storage time was also incorporated for the land application treatment as a large number of land application systems now have a storage capacity.

Variables to be assessed for each treatment were; nitrogen (N), phosphorus (P), potassium (K), biological oxygen demand (BOD), total solids (TS), *Escherichia coli* (*E. coli*, EC) and chemical oxygen demand (COD). Potassium has been modelled as farmers are beginning to identify it as a potential cause of reduced productivity in areas of land application of FDE and Chemical Oxygen Demand (COD) has been modelled for the ENBR ABR/SBR system as it is an important parameter in the efficiency of the systems operation. Volume was also modelled to monitor the practicality when applied to farm scale system. Data was then sourced from previous studies to form a model of expected final effluent or leachate quality. The assumption was made for all relevant calculations that density stays the same (solids < 5%).

3.2 Symbols

i = initial

sf = sand filter

uv = UV disinfection

S = SBR

AD = anaerobic digester

ct = ClearTech

TP = two pond treatment

la = land application

l = lactation length

x = variable

C = concentration

in = initial

z = soil type

b = BioClean

n = number (cows)

m = mass

η = efficiency (change %)

t = time

b = milking

fp = feed pad

w= water

h = hand held hose

sc = scrape

f = floodwash

ss = solids separation

ww = weeping wall

fs = fixed screen

sc =scrape

y = volatilisation

sp = storage pond

e = manure

V = volume of liquid fraction

p = solids separation partitioning constant

3.3 Inputs

Where x = N, P or K

m_{in} is input kg/100 cows/yr. This formula was used to convert x input into m/cow/day for initial mass (m_i)

$$m_i = m_{in} \div t_l \div n \div a$$

Where,

m_{in} = input data m specific to feed combination

t_l = is lactation length

n = 100 cows

a = 1000 which is the conversion rate from kg to g

m_i = initial mass

$$C_{ix} = m_{ix} \times V_i$$

Where,

C_i = initial concentration and,

V_i = initial volume

where x = BOD, TS or EC

$$C_{inx} = C_{ix}$$

As input data concentration (C_{in}) is equal to the initial concentration (C_{in})

BOD and TS conversion to mass

$$m_{ix} = C_{ix} \times V_{ix}$$

3.4 Volume changes

Where x = N, P, K, BOD, TS or EC

$$V_i = V_w + V_e$$

Where,

V_w = volume of water

V_w = either V_h or V_f or V_{sc}

Where,

h = hand held hose

f = flood wash

sc = scrape

V_e = volume of manure

$$V_e = e \times (t_b + t_{fp})$$

Where,

e = manure constant

V_e = volume of manure

t_b = average time at milking parlour (daily)

t_{fp} = time on feed pad (daily)

$$V_{ss} = V_i - (V_i \times \eta_{ssv})$$

V_{ss} = volume of liquid after solid separation

V_i = initial volume

η_{ssv} = solids separation efficiency

Where

η_{ssv} = either η_{hv} or η_{fv} or η_{scv}

ww = weeping wall

fs = fixed screen

sp = screw press

$$V_{ct} = V_i \times \eta_{ctv}$$

V_{ct} = volume of liquid fraction after ClearTech treatment

V_i = initial volume

η_{ctv} = ClearTech liquid fraction efficiency

$$V_{tp} = V_{ss})$$

Volume after two pond treatment (V_{tp}) equals initial volume (V_i)

$$V_{la} = V_{ss}$$

Volume after land application (V_{la}) equals volume after solids separation (V_{ss})

$$V_{AD} = V_{ss} \times (1 - \eta_{ADv})$$

V_{AD} = Volume of liquid fraction of anaerobic digestant

η_{ADv} = solid fractionation efficiency of anaerobic digestion

$$V_S = V_{AD} \times (1 - \eta_{Sv})$$

V_s = Volume of liquid fraction after SBR treatment

η_{Sv} = solid fractionation efficiency of SBR

$$V_{sf} = V_S$$

Volume after SBR (Vs) equals volume of sand filter discharge (V_{sf})

$$V_{sf} = V_{UV}$$

Volume after UV disinfection (V_{UV}) equals volume after sand filtration (V_{sf})

3.5 Mass and concentration changes

Where x = N, P, K, BOD or TS

Solids separation = ss

$$m_{ssx} = m_{ix} - (m_{ix} \times p_x \times \eta_{ssx})$$

m_{ssx} = mass of x after solids separation

m_{ix} = mass of x initially

p_x = solids partitioning constant for x

η_{ssx} = solid separation efficiency of x

Where,

η_{ssx} = either η_{wwx} or η_{fsx} or η_{spx}

ww = weeping wall

fs = fixed screen

sp = screw press

ClearTech

$$m_{ctx} = m_{ix} \times (1 - \eta_{ctx})$$

m_{ctx} = mass of x in liquid fraction after ClearTech treatment

m_{ix} = initial mass of x

η_{ctx} = efficiency of ClearTech removal of x

$$C_{ctx} = m_{ctx} \div V_{ct}$$

V_{ct} = volume of ClearTech liquid fraction

Two pond treatment

$$C_{tpx} = C_{ssx} \times (1 - \eta_{tpx})$$

C_{tpx} = concentration of x in liquid fraction after two pond treatment (TPT)

C_{ssx} = concentration of x in liquid fraction after solid separation

η_{tpx} = efficiency of TPT removal of x

$$m_{tpx} = C_{tpx} \times V_{ct}$$

Anaerobic digester

$$m_{ADx} = m_{ssx} \times (1 - \eta_{ADx})$$

m_{ADx} = mass of x after anaerobic digestion

m_{ssx} = mass of x in liquid fraction after solids separation

η_{ADx} = efficiency of anaerobic digestion removal of x

$$C_{ADx} = m_{ADx} \div V_{AD}$$

C_{ADx} = concentration of x in anaerobic digestion liquid fraction

V_{AD} = volume of anaerobic digestant liquid fraction.

Sequencing Batch Reactor (SBR)

$$m_{Sx} = m_{ADx} \times (1 - \eta_{Sx})$$

M_{Sx} = mass of x after SBR treatment

M_{ADx} = mass of x in liquid fraction after anaerobic digestion

η_{Sx} = efficiency of SBR removal of x

$$C_{Sx} = m_{Sx} \div V_S$$

C_{Sx} = concentration of x in SBR liquid fraction

V_S = volume of SBR liquid fraction.

Sand Filter

$$m_{sfx} = m_{Sx} \times (1 - \eta_{sfx})$$

M_{Sx} = mass of x after sand filtration

M_{Sx} = mass of x in liquid fraction after SBR

η_{sfx} = efficiency of sand filter removal of x

$$C_{sfx} = m_{sfx} \div V_{sf}$$

Csf_x = concentration of x in sand filter discharge

V_{sf} = volume of sand filter discharge.

Where x = P, K, BOD or TS

Land Application

$$m_{lax} = m_{ssx} \times \eta_{zx}$$

m_{lax} = mass of x in leachate

m_{ssx} = mass of x in liquid fraction after solids separation

η_{zx} = soil type efficiency for the removal of x

Where z may be poorly drained soil or well-drained soil

Where x = N

Land Application

$$m_{lax} = (m_{ssx} - (y \times t_{sp}) \times \eta_{zx}$$

m_{lax} = mass of x in leachate

m_{ssx} = mass of x in liquid fraction after solids separation

η_{zx} = soil type efficiency for the removal of x

Where z may be poorly drained soil or well-drained soil

y = volatilisation per month

t_{sp} = time of effluent storage in pond (months).

3.6 Constants

This section tabulates the constants used to model initial volumes and concentrations.

All values are means of results from random number generation (350 values were generated to calculate each mean).

Table 10: Washdown and initial concentration constants.

	Variable	Value
Volume of water for washdown (Vw, l/cow)	Hand held hose	78.0
	Flood wash	45.8
	Scrape	13.7
Initial concentration (g/m^3)	BOD	970
	TS	3,562
	EC	259,599
	COD	11,343

Table 11: Description of different feed combinations.

G/0	All grass
M/0	no feed pad, 2tDM/ha maize silage in paddock
M/1	2tDM/ha maize silage fed on feed pad, cows on for 1 hr
M/2	2tDM/ha maize silage fed on feed pad, cows on for 2 hrs
4M/2	feed comparison, 2 hrs on feed pad, 4tDM/ha/yr. maize silage
4G/2	feed comparison, 2 hrs on feed pad, 4tDM/ha/yr. grass silage

Table 12: Feed combination constants for initial concentrations.

g/m3	**G/0**	**M/0**	**M/1**	**M/2**	**4M/2**	**4G/2**
N	228	318	493	573	647	655
P	26	37	5	75	67	80
K	264	308	447	531	615	739

Table 13: Solids separation concentration constants.

Concentration constant - solids separation	
Particle size	**2mm**
Percentage of TS	34%
Percentage of N	7%
Percentage of P	4%
Percentage of K	0%
Percentage of BOD	34%

3.7 Efficiencies

This section tabulates the efficiencies used to model the change for each treatment.

Table 14: Solids separation efficiencies.

Solids separation efficiency	
Weeping wall	100%
Screw press	88%
Fixed screen	69%

Table 15: ClearTech efficiencies.

ClearTech efficiencies		
	Liquid change	**Solid change**
N	20.707%	111%
P	0.733%	140%
K	52.268%	46%
BOD	18.440%	89%
TS	0.398%	144%
E. *coli*	0.025%	11%

Table 16: Land Application efficiencies.

Land application capture efficiency		
	Poorly drained	**Well drained**
N	20%	12%
P	2%	0%
K	0%	3%
BOD	2%	0%
TS	2%	0%
E. *coli*	9%	1%

Table 17: Two pond treatment efficiencies.

Two pond treatment overall efficiency	
N	62.21%
P	36.33%
K	0.11%
BOD	85.45%
TS	92.64%
E. *coli*	72.84%

Table 18: Anaerobic digestion efficiencies.

Anaerobic digestion/ primary sedimentation efficiency	
N	63%
P	64%
K	0%
BOD	76%
TS	74%
E. *coli*	10%
COD	99%
Volume	7%

Table 19: Sequencing batch reactor efficiencies.

SBR efficiency	
N	89%
P	93%
K	0%
BOD	97%
TS	100%
E. *coli*	10%
COD	89%
Volume	8%

Table 20: Sand filter efficiencies.

Sand filter efficiency	
N	45%
P	44%
K	0%
BOD	91%
TS	72%
E. *coli*	100%
UV disinfection efficiency	
E. *coli*	100%

3.8 Process design and operating conditions

3.8.1 BioClean design

An example of how BioClean would be designed is in Figure 12 below. The system design is based on previous studies on the enhanced biological removal of nitrogen and phosphorus (EBNR). The diagram does not include the sand filter or UV reactor.

Figure 12 shows the potential layout of the system with weeping wall solids separation already present at the end of a feed pad. The ABR and SBR are sitting at ground level, with the weeping wall below (due to the fall of the feed pad). Instead of a sump in the ground after the weeping wall, to collect the liquid out flow, it is suggested that the usual collection area is dug down about 1m into the ground and extended. This is to reduce the height required to pump up into the ABR, as a sump would likely be a further 2m deep (total 3m deep from bottom of current weeping wall drain). This not only increases the head to pump up (in comparison to extending the weeping wall drain area), it also is potentially an unreachable depth for a digger. The collection area is important to enable the intermittent filling of the ABR to improve its operation efficiency. In the case of other solids separation systems, a sump (2.7m height, 25,000L, $4,170) would provide sufficient storage and would be suitable due to the separation occurring at or above ground level.

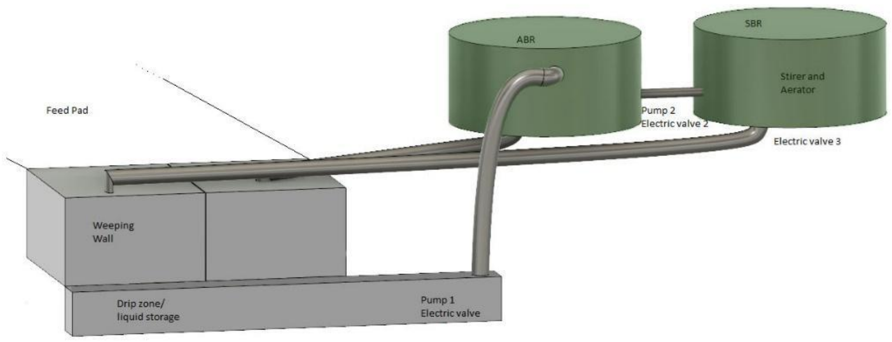

Figure 12: Visual representation of potential layout.

The return pipes from each tank feed both sides of the weeping wall. This adaption (having two sides to the weeping wall) is important as whilst one side of the weeping wall is in operation the other side can be drying further. This enables the solids to be composted once a level of approximately 55% is reached. It also increases the manageability and utilisation of the solids through land application. The solids can be integrated into the soil during cultivation for cropping and/or pasture renewal. The higher solids content reduces the volume, increases the nutrient concentration and reduces the restrictions on when and where it can be applied thereby potentially improving the utilisation potential of the nutrients in the FDE. Restrictions to applying effluent that may be mitigated by applying treated solids as opposed to raw FDE include, slope, water holding capacity and saturation level.

3.8.2 Operating conditions

There are many factors that affect the operating efficiency of the BioClean process. These factors include; temperature, pH, nutrient content of influent, hydraulic retention time, sludge retention time, size and shape of the AD and SBR. For the function of the SBR the number, order and length of phases are major determinants of efficiency. To increase the accuracy of the model created, where possible, data from studies operating under similar conditions has been used.

Anaerobic digestion is typically used for energy production from dairy effluents. The conditions required to maximise energy production (methane production) are different from those required to maximise effluent ‘cleaning’ or removal of nutrients, BOD, TS, *Escherichia coli* and other impurities. Anaerobic digestion can occur at psychrophilic (below 20^oC) temperatures but generally digesters operate at thermophilic or mesophilic (55^oC and 35^oC respectively)(Ward, Hobbs et al. 2008).

To set conditions for the effective operation of this technology, a study into the specific impact on this system would be needed, however some suggestions have been made below, which have been taken from previous studies off which the data was sourced for this model

Table 21: Suggested operating conditions for BioClean technology.

	Condition	Limit/Range	
EBNR	Temperature	>12°C	Phosphorus removal is restricted below this
	COD	220 ±10 - 800±20 mg COD/L	For optimal COD/P ratio of around 40 mg $COD/mg\ PO_4^-P$.
	P	5 ±0.5 to 20 ± 2 mg PO_4^- P/L	
AD	Temperature	Ambient/mesophilic	Anaerobic digestion

3.9 Data source and assumptions

The model created predicts the performance of three currently available techniques for the treatment and/or handling of FDE with the proposed system of FDE treatment (BioClean) which is based off technologies used in waste water treatment. Anaerobic digestion (AD) followed by a nitrifying denitrifying (N/D) and enhanced biological phosphorus removal (EBPR) sequencing batch reactor (SBR), sand filtration and UV disinfection. The aim of this technology is to produce clear water and a potentially compostable solid. Following the practical model creation an economic model was also created to assess economic viability and potential financial impact of the costs associated with BioClean. All data utilised in this model was sourced from previous studies. Where possible the numbers have been used directly, however at times the data has been adapted to suit.

For the purpose of maintaining consistency across estimations and assumptions, a case study farm was used to enhance visualisation and practical implication understanding. The main use of the case study was for the financial analysis but also impacted design modelling and assumptions made.

3.9.1 Case farm description

Komata Farm is a 121 ha dairy farm in Waikato, New Zealand. The farm runs 280 Jersey Friesian cross cows peak in milk and winters about 240, of which approximately half leave to the runoff for 2 months over the winter period. A feed pad is used in early spring and summer to meet feed requirements. Grass and maize silage (grown on the runoff block) are feed at various rates during this time depending on pasture quality and cover. The feed pad (rubber covered) is also used during the wetter winter months to stand the cows off the paddocks to reduce pugging damage. The farm is run at steady state. Current effluent system meets the area requirements in terms of nutrient leaching and is likely to meet future requirements, however the farmer is a progressive farmer interested in alternatives. The current farm dairy effluent management system on farm is a land application system where all effluent goes through a weeping wall first, which runs down to storage ponds. Effluent from storage pond is sprayed, using a travelling irrigator, at a rate of 12 mm. The effluent area is 25 ha.

In comparison to the rest of the Waikato the case study farm is smaller, but runs about average in terms of cost per kg of milk solids produced and production per cow.

3.9.2 Input variables

This section tabulates the source of data relating to input figures and change percentages used in the Monte Carlo simulation.

Table 22: Source of data relating to FDE composition.

FDE Composition

Component	**Source**
Nitrogen	(DairyNZ 2019)
Phosphorus	(DairyNZ 2019)
Potassium	(DairyNZ 2019)
BOD	(Cameron and Di 2019)
Total Solids	(Cameron and Di 2019)
E *Coli*	(Cameron and Di 2019)
COD	(Tilche, Bacilieri et al. 1999)

Table 23: Source of data relating to solids separation partitioning.

Solids separation partitioning	
Component	**Source**
Nitrogen	(Meyer, L. Ristow et al. 2007)
Phosphorus	(Meyer, L. Ristow et al. 2007)
Potassium	(Meyer, L. Ristow et al. 2007)
BOD	Assumed same as TS
Total Solids	(Meyer, L. Ristow et al. 2007)
E. *Coli*	Assumed same as change in volume (30% in solid output 70% in liquid output)
COD	Same as above

The assumption that solids separation retains particles greater than 2mm with varying efficiency was made. Efficiencies detailed in Table 14.

Table 24: Source of data relating to land application of FDE.

Land Application		
- Assuming best management practice, - Assuming inorganic N fraction behaves like fertiliser and organic N behaves like crop residues - 6% lost to volatilisation on yard, (assumed already accounted for) 2% in sump and 3.3%/ month in pond or 40%/yr in pond(Wheeler, Shepherd et al. 2012).		
Component	**Source**	
	Well drained soil	Poorly drained soil
Nitrogen	Adapted from (Wheeler, Shepherd et al. 2012)Table 2, Waikato Soil.	Adapted from (Wheeler, Shepherd et al. 2012) Table 2, Southland soil.
Phosphorus	Estimated from (Wheeler, Shepherd et al. 2012)	Estimated from (Wheeler, Shepherd et al. 2012)
Potassium	(Mendes, Alves Júnior et al. 2016)	(Mendes, Alves Júnior et al. 2016)
BOD	Nil expected due to no direct losses	Assumed the same as Phosphorus due to run off.
Total Solids	Same as BOD	Same as BOD
E. *Coli*	(Aislabie, Smith et al. 2001)	((McLeod, Aislabie et al. 2003) converted with conversion in (Aislabie, Smith et al. 2001)
COD	-	-

Table 25: Source of data relating to two pond treatment.

Two pond treatment

- Assuming the change percentages account for atmospheric losses
- Assuming 1m^3 of effluent = 1000kg (used to calculate TS change %)
- Assuming conversion of faecal *coli*forms to E. *coli* applies equally to effluent in different situations.

Component	**Source**
Nitrogen	(R.J. Craggs 2003)
Phosphorus	(Hickey, Quinn et al. 1989)
Potassium	ND
BOD	(Hickey, Quinn et al. 1989)
Total Solids	(R.J. Craggs 2003), converted assuming 1 m^3 of FDE = 1000 kg
E. *Coli*	(Hickey, Quinn et al. 1989) figure converted using (Aislabie, Smith et al. 2001)
COD	-

Table 26: Source of data relating Cleartech.

ClearTech removal efficiency

- **All conversion percentages calculated from averages provided**

Component	**Source**
Nitrogen	(Cameron and Di 2019)
Phosphorus	(Cameron and Di 2019)
Potassium	(Cameron and Di 2019)
BOD	(Cameron and Di 2019)
Total Solids	(Cameron and Di 2019)
E. *Coli*	(Cameron and Di 2019)
COD	-

Table 27: Source of data relating Anaerobic Digestion/Primary sedimentation

Anaerobic Digestion/Primary sedimentation

Component	**Source**
Nitrogen	(Bolzonella, Innocenti et al. 2002) (Nishio and Nakashimada 2013)
Phosphorus	
Potassium	
BOD	
Total Solids	
E. *Coli*	
COD	(Bolzonella, Innocenti et al. 2002), and (Bachmann, Beard et al. 1985)

Sequencing Batch reactor

- Assuming farmed animal effluents undergo similar changes
- Assuming well managed,
- Modelled for when active, performance maybe be reduced during initial period whilst microbial activity builds.

Component	**Source**
Nitrogen	(Obaja, Macé et al. 2003), (Bernet and Béline 2009) and (Tilche, Bacilieri et al. 1999)
Phosphorus	(Obaja, Macé et al. 2003), (Bernet and Béline 2009) and (Tilche, Bacilieri et al. 1999)
Potassium	
BOD	
Total Solids	
E. *Coli*	
COD	(Tilche, Bacilieri et al. 1999)(Bortone, Gemelli et al. 1992)

3.9.3 Output measures

The model outputs give the liquid volume and composition for each system or sub system; weeping wall, ClearTech, two pond system, land application, ABR, N/D and EBPR SBR, sand filter and UV disinfection and includes;

- Nitrogen
- Phosphorus
- Potassium
- Escherichia *coli*
- Biological Oxygen Demand
- Chemical Oxygen Demand (for the proposed system only)
- Total solids
- Volume

3.9.4 Variables

To increase accuracy, the model was run for several combinations of variables. Factors that were varied include;

- Cow numbers
- Feed system
- Separation method
- Length of storage time (land application)
- Wash down method
- Soil type (land application).

Table 28: Source of data relating to other variables.

Variable	Source
Feed Combination	(DairyNZ 2019)
Solids separation	
Washdown water volume	Detailed in assumptions made below.
Washdown manure volume	(DairyNZ 2019)

Assumptions

Water used by each method varies widely. All methods include some water use (for plant wash and the milking parlour) however, where a handheld hose is primarily used, water use is much greater than where recycled water (flood wash) and scrapers are used. As it is standard to use a combination of all three methods there is little data on the water use of each method individually. However, water use for cowshed yard wash down is said to vary from 30 L/cow to 100 L/cow (Stewart and Rout 2007).

Volume of water used in each different wash down system was estimated due to the variation in operation of each system affecting the water use. Estimates were based off figures in DairyNZ; Farmfact; Passive systems for effluent solids separation (6-26) and Farmfact; Effluent solids separation using a mechanical system (6-27) (DairyNZ 2012, DairyNZ 2012) and the variation stated by Stewart and Rout 2007.

3.9.5 Costing

The investment analysis was based on the following assumptions;

- Ross and Tracey’s Komata Dairy farm has been used as a case study.
- Cost figures relating to this case study have been reduced to a per cow basis and then multiplied to match the BioClean performance model.
- Income from milk solids calculated from average milk solids produced multiplied by number of cows,

- Income is based on a Fonterra supplier, \$6.45 milk price pay-out with a 15c/share dividend payment.
- Number of shares = milk solids produced; shares valued at \$3.25 (share price on September 4th).
- A contingency of \$10,000 has been added to the development budget as it is an estimate and to ensure that it is if anything closer to over budget than under to show the potential effect on the bottom line.
- Where made, estimations have been made greater as opposed to smaller to align with the above point.

Costings have been sourced from potential suppliers and where information is unavailable have been adapted from similar work conducted on Komata farm.

Table 29: Table of costing and sources.

Cost	Description	Source
ABR	$92,000 for 1000 cows	(Moser, Mattocks et al. 2014)
SBR	Tank, Aerator, Motorised stirrer, Motorised valves (other was added in to cover the cost of piecing it together)	(Farmsource) (Clearpond New Zealand)
SUMP/store	Concrete block storage	$15,000 estimated from personal communication with Paeroa Precast concrete.
Separator	Weeping wall	The assumption has been made that separation already occurs on farm. The costing for constructing a sump (or storage area) post separation has been included for weeping walls. The cost of the sump required for a screw press and/or fixed screen separator is approximately $4,170 + GST. Weeping wall storage is more expensive due to the depth of a weeping wall assuming it is at the end of a feed pad.

Table 29 cont.: Table of costing and sources.

Cost	Description	Source
Separator Effluent pump	Screw press separator Fixed screen Davies Single Channel Waste Pump (D105S) - 6m head - 3inch pipe	The assumption has been made that separation already occurs on farm. The costing for constructing a sump (or storage area) post separation has been included for weeping walls. The cost of the sump required for a screw press and/or fixed screen separator is approximately $4,170 + GST. Weeping wall storage is far more expensive due to the depth of a weeping wall assuming it is at the end of a feed pad. Personal communication with Paeroa Farm Services
Earthworks	20t digger - 8 hours at $200/hr	Personal communication with Ross Buchanan (Dairy Farmer)
Electrical	Estimation based on electrical work done for similar job	Personal communication with Ross Buchanan (Dairy Farmer)
Electronic Valve	- SSBV25-AE - Ball valve 25mm - 9-4V AC/DC Actuator - Normally Closed	Personal communication with Water supply products via website enquiry

Table 29 cont.: Table of costing and sources.

Cost	Description	Source
Aerator	- Two solar powered pumps - Solarfree 1600c Supreme Solar pump S22077 - 1560lph - Comes with battery backup units for sunless days and night use. - Max head height 3.2 (m)	(Clearpond New Zealand)
Clarifier	- 30,000l Tank	(Farmsource)
Sand Filter	4 layers, starting from the bottom; - 0.5-0.75 in rock - .374 in pea gravel - Filter sand - 0.5-0.75 in rock	(United States Environmental Protection Agency 1999) Price estimated based on a gravity discharge sand filter (prices vary widely due to availability of products; however, sand filters are generally known to be low cost for both capital and running costs.
Disinfection	Ultraviolet Light Steriliser for Water Treatment - 9000 burning hrs - 30,000 mW sec/cm^2 - Easy lamp replacement - 200m^3 /hr water treatment - 150kg - 8 inch inlet/outlet diameter	(Alibaba.com)

3.10 Monte Carlo Simulation

Tabulated below are the figures for which 200 random normally distributed numbers were generated. Where possible, standard deviations from reported data were used, otherwise a standard deviation of plus or minus 10% of the average was used. 10,000 repetitions of each scenario were conducted to make a sample data set.

Table 30: Monte Carlo variables (mg/L).

	Reported Data Average	**Parameter output**
Inputs		
BOD	953	969
TS	3,173	3,562
E. *coli* (cfu/100ml)	247,718	259,599
COD	10,508	11,342.81
	G/0	
N	590	511
P	70	59
K	540	593
	M/0	
N	668	713
P	80	83
K	668	692
	M/1	
N	1,008	1,142
P	12	13
K	1,044	1,034
	M/2	
N	1,348	1,367
P	160	178
K	1,396	1,267

Table 30 cont.: Monte Carlo variables(mg/L)

	Reported Data Average	Parameter output
	4M/2	
N	1,360	1,543
P	164	160
K	1,460	1,468
	4G/2	
N	1,588	1,563
P	184	190
K	1,668	1,763
Solids separation particle size (2mm)		
N	9%	0.074
P	9%	-0.045
K	0%	-0.005
BOD	10%	0.099
TS	30%	0.338
Solids separation operation efficiency		
Weeping wall	95%	1.005
Screw press	85%	0.876
Fixed screen	70%	0.686
Volume calculation		
Manure per half hour	1.5	1.3
Water volume (l)		
hand held hose	70.0	77.9
flood wash	50.0	45.8
scrape	15.0	13.7
Litres manure		
hand held hose	2	1.825
flood wash	10	9.979
scrape	20	20.733

Table 30 cont.: Monte Carlo variables

	Reported Data Average	**Parameter output**
ClearTech Liquid efficiency		
N	21.94%	0.2071
P	0.63%	0.0073
K	46.37%	0.5227
BOD	17.04%	0.1844
TS	0.38%	0.0040
E. *coli* (cfu/100ml)	0.02%	0.0002
ClearTech Solid efficiency		
N	1.11	1.1150
P	1.58	1.4000
K	0.49	0.4577
BOD	0.81	0.8918
TS	1.41	1.4445
E. *coli* (cfu/100ml)	0.09	0.1081
Land application Poorly drained		
N	20%	0.199
P	2%	0.019
K	0.12%	0.001
BOD	2%	0.017
TS	2%	0.022
E. *coli* (cfu/100ml)	8%	0.086
Land application Well drained		
N	10%	0.118
P	0.00%	0.000
K	3%	0.033
BOD	0.00%	0.000
TS	0.00%	0.000
E. *coli* (cfu/100ml)	0.50%	0.005

Table 30 cont.: Monte Carlo variables

	Reported Data Average	**Parameter output**
Two Pond Treatment overall efficiency		
N	64%	0.62
P	34.56%	0.36
K	0.10%	0.00
BOD	94.54%	0.85
TS	80%	0.93
E. *coli* (cfu/100ml)	84%	0.73
AD		
N	65%	0.63
P	80%	0.64
K	0.10%	0.00
BOD	80%	0.76
TS	80%	0.74
E. *coli* (cfu/100ml)	10%	0.10
COD	90%	0.99
Volume	8%	0.07
SBR (N/D and P removal)		
N	97%	0.89
P	98%	0.93
K	0%	0.00
BOD	98%	0.97
TS	95%	1.07
E. *coli* (cfu/100ml)	10%	0.10
COD	99%	0.89
Volume	8%	0.08

Table 30 cont.: Monte Carlo variables

	Reported Data Average	Parameter output
Sand Filter		
N	40%	0.45
P	40%	0.44
K	0%	0.00
BOD	98%	0.91
TS	78%	0.72
E. *coli* (cfu/100ml)	99%	1.10
UV treatment		
E. *coli* (cfu/100ml)	99.9%	1.13

3.11 Student T – test

To assess the significance of the variation identified in the data. Two tailed Student T-tests were carried out using Excel with a significance level of 0.05. The significance of the difference between data populations of each variable was compared between scenarios and treatment system.

For example, BioClean x in scenario 112 was compared with BioClean x in scenario 94, 110, 113, 114, 118, 124, 130, 328 and 544. The data population of BioClean x in scenario 112 was also compared within scenario 112, against other populations of x (land application, two pond treatment or ClearTech).

3.12 Selected scenarios

Scenarios that have been analysed and will be referenced in the discussion are; 94 110, 112, 113, 114, 118, 124, 130, 328 and 544. The variables are detailed in Table 29 below. Scenario 112 has been selected as the constant and comparisons have been made against it to show the impact of changing each variable. An asterix (‘*’) has been used to highlight the variable that is different from scenario 112. Scenario 94 has two changed variables highlighted by 2 asterix in each changed variable. Scenario 94 can be compared to Scenario 130 as there is only one difference between the two situations. The comparison of the impact of a holding pond has been compared for poorly drained soil (scenarios 94 and 130) rather than well drained soil as it is more likely that a farm with poorly drained soil will require a holding pond than one with well-drained soil. This makes the analysis more representative of an on-farm situation.

Table 31: Description of selected scenarios, '*' to show variations.

Situation	Feed combination	Solids separation	Soil drainage	Holding pond (y/n)	Holding period average (months)	Wash down method
94	M/2	Weeping wall	Poorly Drained**	Yes**	2	hand held hose
110	M/0**	Weeping wall	Well Drained	no	2	hand held hose
112	M/2	Weeping wall	Well Drained	no	2	hand held hose
113	4M/2*	Weeping wall	Well Drained	no	2	hand held hose
114	4G/2*	Weeping wall	Well Drained	no	2	hand held hose
118	M/2	Screw press*	Well Drained	no	2	hand held hose
124	M/2	Fixed screen*	Well Drained	no	2	hand held hose
130	M/2	Weeping wall	Poorly Drained*	no	2	hand held hose
328	M/2	Weeping wall	Well Drained	no	2	flood wash*
544	M/2	Weeping wall	Well Drained	no	2	Scrape*

Chapter 4. Results and discussion

4.1 Nitrogen

Nitrogen is one of the main drivers of environmental degradation currently. Because of this it is the subject of many regional council's regional plan legislation. A treatment method that results in significant improvement in the loss of nitrogen is likely to be of significant interest for farmers, legislative bodies and society. In the case of nitrogen, farmers interest is stemmed by both the desire to reduce environmental impact and the requirement by law to meet moving targets for loss of N.

When comparing the change percentages of the three scenarios (112, 114 and 130) by treatment (Land application, ClearTech and BioClean), land application performs the best on average and ClearTech is associated with the least change on average. For scenario 112, nitrogen removal by BioClean is the most efficient at an average of 98% removal. Land treatment follows closely behind with 91% removal and ClearTech is predicted to remove 55% of nitrogen on average. This trend is repeated for scenarios 114 and 130 as shown in Table 32, Table 33 and Table 34 with similar change percentages.

Table 32: Table showing scenario 112 mean (mg/L), standard deviation and percentage change for Land application, ClearTech and BioClean.

112							
Input	**N**	**P**	**K**	**BOD**	**TS**	**EC (cfu/100ml)**	**COD**
Mean	615	73	637	954	3171	247,853	10,496
SD	83	10	84	95	318	24,542	1,052
Land application							
Mean	58	0	20	0	0	38	208
SD	10	0	3	0	0	6	48
Change	-91%	-100%	-97%	-100%	-100%	-100%	-98%
ClearTech							
Mean	275	1	603	333	25	54	1,414
SD	47	0	102	46	4	8	242
Change	-55%	-99%	-5%	-65%	-99%	-100%	-87%
BIOCLEAN							
Mean	13	13	772	1	12	1,252	3
SD	10	10	104	2	12	1,547	3
Change	-98%	-82%	21%	-100%	-100%	-99%	-100%

Table 33: Table showing scenario 114 mean (mg/L), standard deviation and percentage change for Land application, ClearTech and BioClean.

114							
Input	**N**	**P**	**K**	**BOD**	**TS**	**EC (cfu/ 100ml)**	**COD**
Mean	201	24	201	584	1946	152,002	6,438
SD	164	20	164	471	1567	122,445	5,187
Land application							
Mean	46	1	0	10	35	404	83
SD	192	19,449	52	6	96	63	209
Change	-77%	-98%	-100%	-98%	-98%	-100%	-99%
ClearTech							
Mean	110	0	232	248	18	33	564
SD	91	0	192	203	15	27	466
Change	-45%	-98%	15%	-58%	-99%	-100%	-91%
BioClean							
Mean	4	4	297	1	8	0	2
SD	6	6	242	1	13	0	3
Change	-98%	-83%	48%	-100%	-100%	-100%	-100%

Table 34: Table showing scenario 130 mean (mg/L), standard deviation and percentage change for Land application, ClearTech and BioClean.

130							
Input	**N**	**P**	**K**	**BOD**	**TS**	**EC (cfu/100ml)**	**COD**
Mean	329	39	329	952	3,171	247,550	10507
SD	46	5	45	94	322	24,599	1,038
Land application							
Mean	75	1	0	17	57	658	136
SD	14	0	0	3	9	112	32
Change	-77%	-98%	-100%	-98%	-98%	-100%	-99%
ClearTech							
Mean	179	1	381	404	30	54	922
SD	32	0	67	58	4	8	164
Change	-45%	-98%	16%	-58%	-99%	-100%	-91%
BIOCLEAN							
Mean	9	9	486	1	15	13,241	1,027
SD	7	7	70	2	14	9,982	1,257
Change	-97%	-78%	48%	-100%	-100%	-95%	-90%

Treated effluent outflow from BioClean is predicted (for scenario 112) to contain 13 mg/L of total nitrogen. Which when multiplied by the output volume (27 m^3) totals 351 grams of nitrogen per day. Assuming a lactation period of 271 days this totals, 95kg N per year. Maximum discharge concentration for the Pahiatua WWTP for the 2008 -2013 period was 31 mg/L and the mean discharge for 2013 was 13.3 mg/L. This shows that the performance of BioClean technology is predicted to be similar to that of currently consented discharges regarding nitrogen content. The histogram of data relating to this (Figure 13), shows that the likelihood of the discharge effluent nitrogen content being below the simulated mean (13 mg/L) is higher than the likelihood of it being greater. The frequency distribution of total nitrogen in the BioClean treated effluent shows that within the simulated data the most frequent outcome was in the range of 2.27 mg N/L ≤ 0 >3.03 mg N/L, with 252 data points within this range. This level of nitrogen concentration is likely to be sufficient to enable discharge from dairy farms to water if it could be replicated in practice.

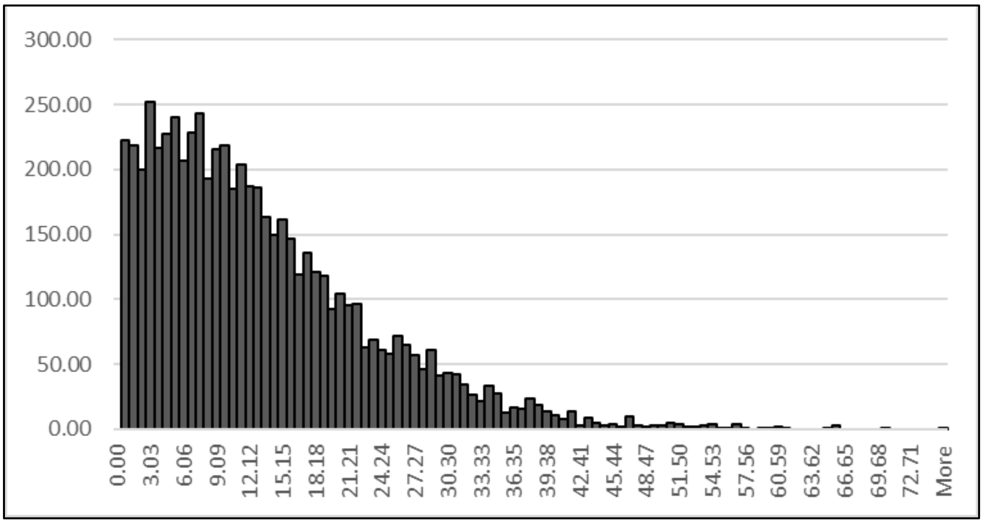

Figure 13: Scenario 112 nitrogen histogram of BioClean final data.

The difference in treatment removal efficiency was found to be statistically significant for nitrogen in all cases ($p<0.05$). This shows that even though in some scenarios (112 for example) the change percentage achieved by BioClean is only marginally greater (98% vs 91%) than land application, that difference has been calculated to be statistically significant ($p<0.05$).

Table 35: Scenario 94 p-values.

94	N	P	K	BOD	TS	*E. coli*	COD
CT vs BioClean	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
LA vs BioClean	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
TPT vs BioClean	0	0	0	0	0	0	
AD vs SBR	0	0	0	0	0	0	0
SBR vs SAND	5.9565E-255	0	0.604865	0	0	0	0
SAND vs UV						0	

Table 36: Scenario 110 p-values.

110	N	P	K	BOD	TS	*E. coli*	COD
CT vs BioClean	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
LA vs BioClean	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
TPT vs BioClean	0	0	0	0	0	0	
AD vs SBR	0	0	0	0	0	0	0
SBR vs SAND	6.9665E-250	0	0.625228	0	0	0	0
SAND vs UV						0	

Table 37: Scenario 112 p-values

112	N	P	K	BOD	TS	*E. coli*	COD
CT vs BioClean	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
LA vs BioClean	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
TPT vs BioClean	0	0	0	0	0	0	
AD vs SBR	0	0	0	0	0	0	0
SBR vs SAND	4.9966E-250	0	0.601517	0	0	0	0
SAND vs UV						0	

Table 38: Scenario 113 p-values.

113	N	P	K	BOD	TS	*E. coli*	COD
CT vs BioClean	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
LA vs BioClean	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
TPT vs BioClean	0	0	0	0	0	0	
AD vs SBR	0	0	0	0	0	0	0
SBR vs SAND	1.4368E-254	0	0.612764	0	0	0	0
SAND vs UV						0	

Table 39: Scenario 114 p-values.

114	N	P	K	BOD	TS	*E. coli*	COD
CT vs BioClean	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
LA vs BioClean	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
TPT vs BioClean	0	0	0	0	0	0	
AD vs SBR	0	0	0	0	0	0	0
SBR vs SAND	1.2854E-242	0	0.620115	0	0	0	0
SAND vs UV						0	

Table 40: Scenario 118 p-values.

118	N	P	K	BOD	TS	*E. coli*	COD
CT vs BioClean	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
LA vs BioClean	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
TPT vs BioClean	0	0	0	0	0	0	
AD vs SBR	0	0	0	0	0	0	0
SBR vs SAND	1.1865E-246	0	0.621332	0	0	0	0
SAND vs UV						0	

Table 41: Scenario 124 p-values.

124	N	P	K	BOD	TS	*E. coli*	COD
CT vs BioClean	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
LA vs BioClean	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
TPT vs BioClean	0	0	0	0	0	0	
AD vs SBR	0	0	0	0	0	0	0
SBR vs SAND	8.3098E-258	0	0.623874	0	0	0	0
SAND vs UV						0	

Table 42: Scenario 130 p-values.

130	N	P	K	BOD	TS	*E. coli*	COD
CT vs BioClean	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
LA vs BioClean	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
TPT vs BioClean	0	0	0	0	0	0	
AD vs SBR	0	0	0	0	0	0	0
SBR vs SAND	5.5898E-255	0	0.621377	0	0	0	0
SAND vs UV						0	

Table 43: Scenario 328 p-values.

328	N	P	K	BOD	TS	*E. coli*	COD
CT vs BioClean	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
LA vs BioClean	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
TPT vs BioClean	0	0	0	0	0	0	
AD vs SBR	0	0	0	0	0	0	0
SBR vs SAND	9.2191E-251	0	0.611496	0	0	0	0
SAND vs UV						0	

Table 44: Scenario 544 p-values.

544	N	P	K	BOD	TS	*E. coli*	COD
CT vs BioClean	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
LA vs BioClean	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
TPT vs BioClean	0	0	0	0	0	0	
AD vs SBR	0	0	0	0	0	0	0
SBR vs SAND	2.6696E-254	0	0.621163	0	0	0	0
SAND vs UV						0	

The change percentage figures for nitrogen illustrates the impact of changing variables in the scenarios. BioClean data results in 98%, 98% and 97% removal efficiency across the three scenarios (112, 114 and 130). Scenario's 124 and 328 (Table 45 and Table 46) support this again with change percentages for nitrogen of 97% and 98% respectively. BioClean's removal is therefore consistent. The impact of changing variables influencing the input nitrogen concentration and volume are not likely to impact the nitrogen removal performance of BioClean.

Table 45: Scenario 328; mean (mg/L), standard deviation and change percentages for Land application, ClearTech and BioClean.

328							
Input	**N**	**P**	**K**	**BOD**	**TS**	**EC (cfu/100ml)**	**COD**
Mean	476	6	493	953	3,176	248,122	10513
SD	64	1	67	95	316	24,702	1047
Land application							
Mean	90	0	1	14	47	633	161
SD	87	1	1	13	52	778	152
Change	-81%	-98%	-100%	-99%	-99%	-100%	-98%
ClearTech							
Mean	213	0	467	332	25	55	1,095
SD	36	0	80	47	3	8	188
Change	-55%	-99%	-5%	-65%	-99%	-100%	-90%
BIOCLEAN							
Mean	10	10	598	1	12	16,260	1,271
SD	8	8	83	2	11	12,253	1,588
Change	-98%	77%	21%	-100%	-100%	-93%	-88%

Table 46: Scenario 124; mean, standard deviation and change percentages for Land application, ClearTech and BioClean.

124							
Input	**N**	**P**	**K**	**BOD**	**TS**	**EC (cfu/100ml)**	**COD**
Mean	328	39	329	952	3,173	247,410	10,502
SD	46	5	46	95	318	24,609	1,041
Land application							
Mean	75	1	0	17	57	658	135
SD	14	0	0	3	9	112	32
Change	-77%	-98%	-100%	-98%	-98%	-100%	-99%
ClearTech							
Mean	179	1	379	404	30	54	922
SD	32	0	66	60	4	8	163
Change	-45%	-98%	15%	-58%	-99%	-100%	-91%
BIOCLEAN							
Mean	9	9	486	1	15	13,241	1,027
SD	7	7	70	2	14	9,982	1,257
Change	-97%	-78%	48%	-100%	-100%	-95%	-90%

The performance of land application varies with each scenario. The influence of feeding grass silage as opposed to maize silage (scenario 114 compared to 112) reduced the removal of nitrogen from 91% to 77%. This is the direct impact of increased loading of nitrogen on the soil resulting in increased losses. The difference between scenarios 112 and 114 for land application nitrogen is statistically significant ($p<0.05$). This comparison exaggerates the impact of the change in feed composition due being between 2 kg DM maize silage and 4 kg DM grass silage. However, the difference between scenarios 113 and 114 (4 kg DM maize silage versus 4 kg DM grass silage) is also statistically significant ($p<0.05$). Grass silage has a much higher protein content (nitrogen) than maize silage, therefore the nitrogen input into the system is increased.

Table 47: Land application loss p-values comparing scenario 112 against each other scenario (significance p<0.05).

LAND APPLICATION						
112 vs	N	P	K	BOD	TS	E. *coli*
94	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
110	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
113	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
114	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
118	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
124	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
130	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
328	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
544	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
94 vs 130	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Like land application, the performance of ClearTech changes with the change in input volume and concentration.

4.2 Phosphorus

Eutrophication is the result of high levels of both nitrogen and phosphorus in waterways. Although nitrogen is currently the main focus of governing bodies in terms of the impact of dairy farming and the agricultural industry, phosphorus is part of the problem. Because of this it is likely that once nitrogen has been addressed the focus will move to phosphorus. For this reason, it is important that there is an understanding of the phosphorus removal from FDE during the treatment/handling process.

The removal of phosphorus by BioClean is on average lowest across all scenarios. Removal of phosphorus in scenario 112 was 82% on average resulting in a residual P level of 13mg/L, with a standard deviation of 10mg/L (Table 32). When compared to the average residual’s for land application, ClearTech (0 mg/L and 1 mg/L) and Pahiatua WWTP (0.1 mg/L in 2013) it is 10 times larger. The difference in removal of phosphorus between the treatments within scenario 112 were found to be significantly different ($p<0.05$). With current and proposed legislative requirements this performance is not expected to be accepted for discharge to water. This is due to the fact that Pahiatua WWTP was expected to improve its performance and reduce the residuals it was discharging. The change was from a mean of 4.7 mg/L in 2008 to 0.1 mg/L in 2012 and had a maximum discharge rate of 7mg/L.

Phosphorus removal by BioClean is based on data regarding the removal performance of the anaerobic digester or sequencing batch reactor individually. The impact of using an anaerobic digester and sequencing batch reactor in sequence was studied by Obaja et al with pig manure as the influent (Obaja, Macé et al. 2003). The study was focused on the performance of the SBR, and it found high levels of phosphorus (97.3%) and nitrogen (99.7%) were removed from the anaerobic digester effluent. This study did not clarify overall how much change occurred (between both the AD and SBR). This study also found that the combination of the anaerobic digester and sequencing batch reactor were able to successfully treat pig manure, despite large variations in the composition of the influent. This is an important finding as FDE would have similar fluctuations in composition, and potentially even more fluctuation due to the farming system in New Zealand. FDE composition is directly related to diet composition. Pastures are not all equal in composition and quality and therefore change of paddock can cause with a change in the composition of the diet. At times of the year cows may graze multiple paddocks in one day providing large dietary variation.

Anaerobic digestion is predicted to reduce the content of COD significantly ($p<0.05$) during the digestion process (Table 32 and Table 37). The presence of COD in the effluent of the anaerobic digester (influent of the SBR) is predicted to be low enough to potentially reduce the efficiency of the enhanced nutrient removal. Enhanced biological removal of phosphorus requires a minimum COD to TP (total phosphorus) ratio of 33 (Akbarzadeh, Khodabakhshi et al. 2012). In scenario 112 this ratio is 3:13. Anaerobic digestion removes COD and phosphorus. The SBR is modelled on the assumption that COD levels are sufficient for efficient removal of phosphorus. This results in the difference between phosphorus levels in the ABR effluent and SBR effluent for scenario 112 are statistically significant. However, the level of COD in the SBR influent (AD effluent) is below that recommended for efficient biological P removal. It is therefore possible that P removal in the SBR is overestimated. The effect of using anaerobic digestion and an EBNR sequencing batch reactor in sequence with dairy manure is unknown. Obaja et al found high rates of phosphorus removal were possible in an EBNR SBR after anaerobic digestion of pig manure. Suggesting that these rates of removal are possible (Obaja, Macé et al. 2003). To achieve maximum biological nutrient removal there is the potential to alter the operating system of the AD and SBR to result in an overall system optimised for the removal of the nutrients. A potential system would be the 2-stage removal of P in both the AD and SBR system. By optimising the process sequence of both the AD and SBR to work together there is the potential for increased removal efficiency.

Phosphorus removal was consistently high by all treatment processes even with changes in the influent concentration and volume. Land application and ClearTech achieved removal rates above 98% for scenarios 112, 114, 124, 130 and 328. These rates of removal resulted in residual phosphorus levels (TP<1.5 mg/L in all cases) similar to that of the Pahiatua WWTP. BioClean technology would need to meet these rates of removal to be a potentially viable product in the future.

The distribution of the residual phosphorus data for BioClean was similar to that of nitrogen, a very one-sided distribution. The histogram data for each scenario is similar (shown in Figure 14, Figure 22 and Figure 23; Appendix 2) suggesting only a small variation in phosphorus removal with the variable changes. This change is however statistically significant.

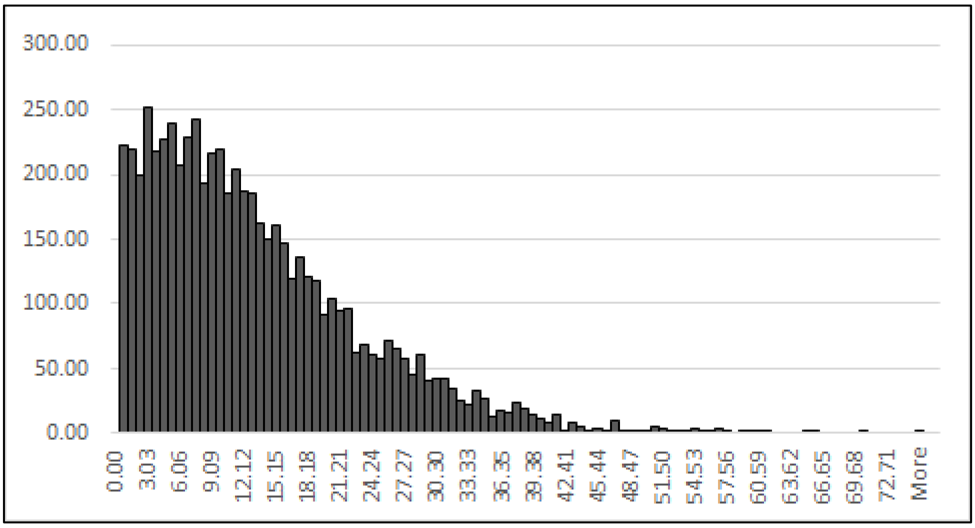

Figure 14: Scenario 112, Histogram of BioClean residual P data.

4.3 Potassium

Potassium has been noted by farmers to be a difficult to manage in relation to the land application of FDE. FDE application rates are driven by the application rate of nitrogen. FDE can have similar or greater levels of potassium when compared with nitrogen. However, potassium is required in much lower levels in the soil for pasture growth. This is leading to the build-up of potassium in the soil to levels that are being associated with poor pasture performance (increased weed content and reduced persistence of pastures). This effect on pastures is represented in this model by high rates of potassium removal with FDE land treatment, showing that high levels of potassium are removed from applied effluent (up to 100% removal).

This may have a positive impact on the receiving environment post land treatment, but the immediate receiving environment is being negatively impacted and this is the environment that has the largest influence of the farms bottom line.

Both ClearTech and BioClean remove some of the potassium from the influent liquid. The difference between these two systems is that the removal in ClearTech binds the potassium up in flocs, these flocs are then applied to the land in the treated effluent portion. The potassium is therefore still applied to the paddocks, it is however bound up in flocs which requires breaking down to release the potassium. This will occur over time but would reduce the impact of potassium in the short term. ClearTech liquid is predicted to have and average residual K for scenario 112 of 603 mg/L, this however was based off a short-term study. As the liquid effluent is recycled, the influent will increase in potassium content and therefore so too will the concentration of K in both the green water (liquid portion) and the treated effluent (termed solids in this model).

The biological nature of BioClean means that the removal of potassium is likely to be as a result of biological activity. It is therefore expected for there to be very low removal rates of potassium (21% in scenario 112). Current legislation including the RMA (1991) and the NPSFM do not include any specific regulation for managing or monitoring potassium in waterways. It is therefore difficult to know what would be acceptable in terms of levels allowed in discharge. Residual potassium averages range from 297 mg/L to 772 mg/L depending on the scenario. However, there are many assumptions relating to the calculations of these figures as potassium is rarely studied in relation to anaerobic digestion, sequencing batch reactor or sand filtration performance. This is reflected by large standard deviations as can be seen in Figure 15 (and Appendix 2) a histogram of the scenario 112 BioClean residual potassium data, where the data ranges from 420 mg K/L to well over 1,300 mg K/L.

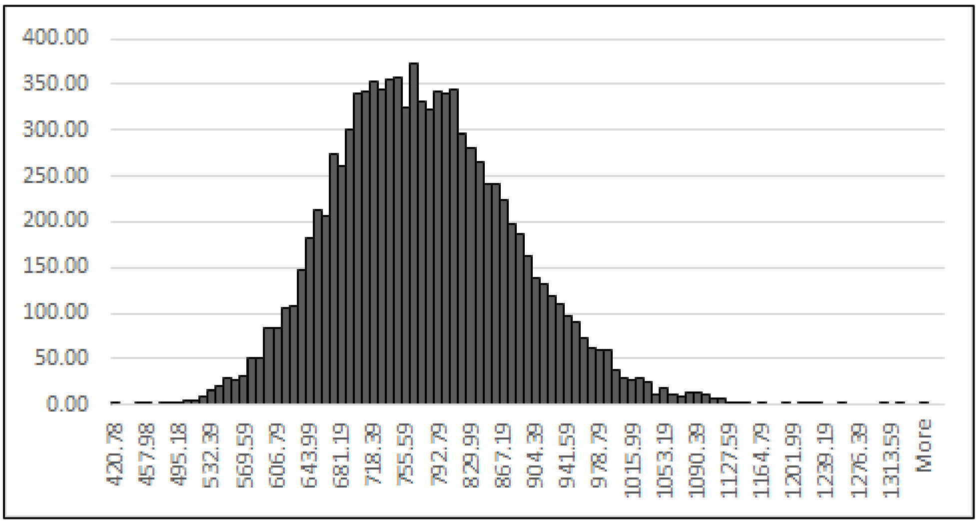

Figure 15: Scenario 112, Histogram of BioClean residual K (mg/L) data.

4.4 *Escherichia coli*

Removal of *Escherichia coli* was found to be greater than 95% for land application, ClearTech and BioClean. The rate of removal was greatest for BioClean. This is directly as a result of the simulation as the removal of *E. coli* was not influenced in any way by treatment. A standard input value was used and the percentage change factors did not alter with any of the variables. BioClean operates UV disinfection, the performance of which can be altered to meet the disinfection requirements. To ensure the UV disinfection in BioClean met standards the UV reactor would be designed to ensure that flow rate and UV intensity was correct. To optimise this correctly, accurate data on the quality of FDE influent would be required.

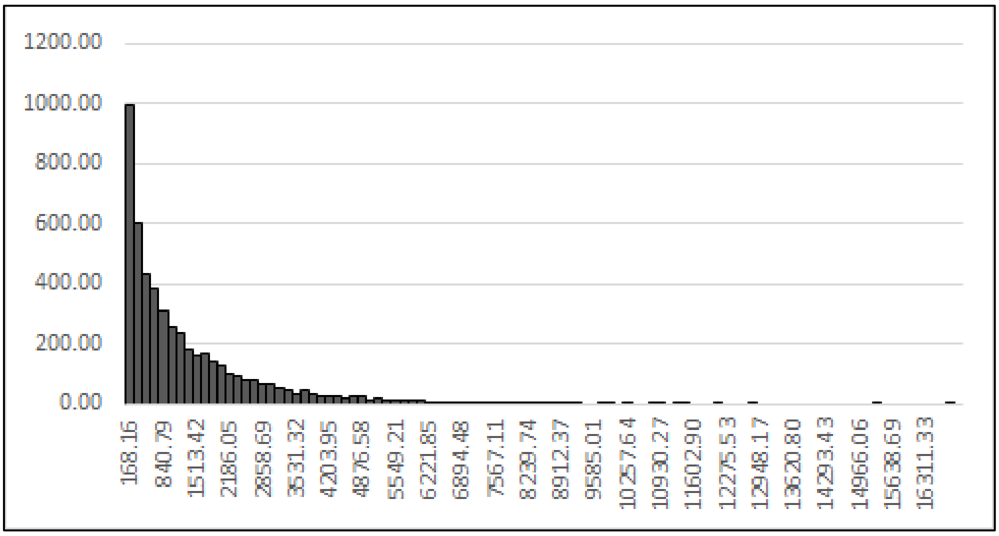

Figure 16: Scenario 112; Histogram of residual *E. coli* after UV disinfection.

The above histogram (Figure 16) shows that there is little variation in the data. It has a one-sided distribution as any results that were less than 0 were removed from the data as it is not possible to have negative *E. coli*. From the distribution of the data you can see that there was a large spread of data. This is similar for the histogram of scenario 328 (Figure 17) where 5,053 of 5,056 data points are first 47 bins and the last 3 data points are spread across the largest 53 bins. These points are potentially outliers and cause the mean to be less representative of the data. The mean UV disinfection *E. coli* residual for scenario 328 is 16,260 cfu/100ml (SD 12,253 cfu/100ml). However, over half the data is below 1,011.97 cfu/100ml. This shows the variability in the data. As with all data there is likely to be a distribution however, the likelihood of UV disinfection performance mirroring this data is low. High levels of consistency can be achieved from UV disinfection and would be expected from effective operation.

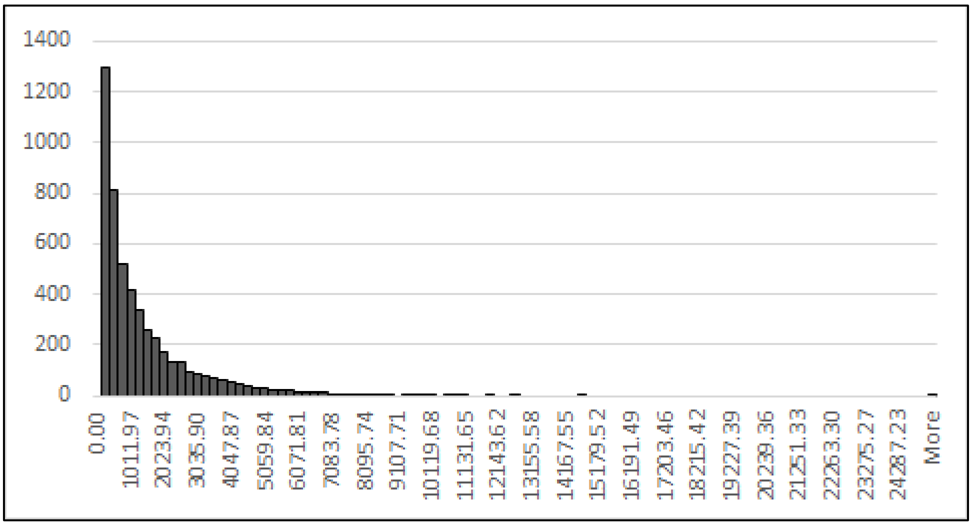

Figure 17: Scenario 328; Histogram of residual *E. coli* after UV disinfection.

Table 48: Scenario 328; mean standard deviation and change % for Land application, ClearTech and BioClean.

328							
Input	**N**	**P**	**K**	**BOD**	**TS**	**EC (cfu/100ml)**	**COD**
Mean	476	6	493	953	3,176	248,122	10513
SD	64	1	67	95	316	24,702	1,047
Land application							
Mean	90	0	1	14	47	633	161
SD	16	0	0	2	7	105	37
Change	-81%	-98%	-100%	-99%	-99%	-100%	-98%
ClearTech							
Mean	213	0	467	332	25	55	1,095
SD	36	0	80	47	3	8	188
Change	-55%	-99%	-5%	-65%	-99%	-100%	-90%
BIOCLEAN							
Mean	10	10	598	1	12	16,260	1,271
SD	8	8	83	2	11	12,253	1,588
Change	-98%	77%	21%	-100%	-100%	-93%	-88%

4.5 Land application

The volume of leachate was assumed to be equal to the applied effluent. This is based on the assumption that effluent applied displaces the water within the soil when it is applied. This is only the case when FDE is applied when the soil is saturated or at field capacity. Working on the assumption that best management practices are being upheld, as assumed for the removal rates, it is unlikely that FDE would be applied at this time. A large portion of New Zealand's soils are not suitable for application of FDE unless a soil deficit is present, and the application rate must be low enough that field capacity is not exceeded. Where this is the case the volume is likely to be significantly lower than modelled due to the uptake by plants and retention within the soil profile.

Loss of nutrients are estimated in this model as loss from root zone. This however, is not an accurate measure or estimate of the nutrients that enter a waterway. Nutrients lost from the root zone are not lost directly to the waterways. Depending on the distance through the catchment, to the above or below ground water way and other factors such as the parent material of the soils, different levels of the leachate actually enter the waterway. The level of which is currently unknown, making the impact of a farms leaching on the waterway unknown.

Currently the most accurate way of estimating nutrient losses on farm is through the use of Overseer. Overseer is a model that calculates leaching based using an accounting approach, assuming that if we know all of the inputs to the system and the processes which affect their endpoint we can accurately estimate the destination of those nutrients. It is a work in progress as there are still many factors that impact the end point of nutrients in a farm system that are not accounted for. It does however give an estimation, to the impact and is what is widely used across New Zealand to set targets for the agricultural industry in terms of nutrient loss.

Comparing the land application results with BioClean data is therefore irrelevant as the land application results are a relating diffuse source of pollution. Whereas the BioClean liquid effluent would potentially be a point source of pollution with the added impact of also applying the solids to land.

4.6 ClearTech

The ClearTech system is realistically a solids separation system that has the added benefits of binding up some nutrients in flocs and the removal of *Escherichia coli*. ClearTech enables quick and easy removal of solids to produce green water for recycling and a treated effluent for land application. This model does not accurately represent the environmental impact of the ClearTech technology as it models the liquid phase which is recycled and where excess is applied to land. However, ClearTech is a great basis for comparison of BioClean, as ClearTech is a new product to the market and the liquid is defined as green water. The ClearTech liquid effluent does not meet standards to be used in a handheld hose and certainly not for discharge to water bodies (rivers and streams). The performance of BioClean must exceed ClearTech in all aspects to be of any use.

ClearTech uses polyferric sulphate (polymerized form of ferric sulphate) as a flocculant. Ferric sulphate is an FDA approved additive for human consumption and has been used for the treatment (removal of phosphorus) in drinking water reservoirs in the UK. However, Cameron and Di found that the concentration of iron (Fe) increased in plant material grown on pasture where effluent treated by ClearTech was applied. This was linked to the iron concentration of the flocculant used (Cameron and Di 2019). There is therefore the potential that over time this may build up in the soil and become a source of contamination. If BioClean achieves similar levels of removal as ClearTech, the benefit of its technology is that it is an organic, biological process, there are no additives so no chance for contamination due to additives. It could be a source of contamination equal to direct land application if it doesn’t achieve removal as expected.

4.7 BioClean

The performance of the BioClean system is only predicted to be greater than ClearTech and Land application for Nitrogen removal and Biological Oxygen demand. Due to the large number of assumptions that went into the calculation of these results it is expected that the performance of BioClean may not be accurately represented. The data used for the simulations were derived from systems where one or maybe two of the components of BioClean were used.

Large standard deviations were also used for this data to account for the fact that a lot of the data was derived and/or collated from many different studies where conditions varied. This was the same for all the data used. As each phase of the BioClean treatment process was modelled in sequence, the standard deviation and therefore the variability of the data increase throughout the system. The change percentages for BioClean are therefore less accurate.

4.7.1 Anaerobic Digester

To ensure influent FDE is well mixed with the activated sludge, addition below the sludge is suggested. This would enable high level of mixing and therefore high levels of contact between the microbes and the influent will be achieved. This method of mixing mitigates the requirement for mechanical agitation and therefore reduces the risk of mechanical failure and cost of running.

The volume of effluent captured daily off a dairy farm is large (greater than 29,000 L for a 400-cow farm). This is restrictive in terms of the anaerobic digester size required. Typical anaerobic digesters have hydraulic retention times of more than 5 days (for AD optimised for methane production). The purpose of anaerobic digestion in this system is as pre-treatment for EBNR SBR. It has a simultaneous function as primary sedimentation and anaerobic digestion. For practical and efficient utilisation of the BioClean technology it is predicted there be a maximum hydraulic retention time of 2 days. With optimal function being an HRT of one day.

A fixed film digester is an option to potentially meet these requirements. The addition of media to the reactor will increase the size of digester required to service the same intake of effluent. Fixed film AD have HRT of 2 – 4 days (Wilkie 2005), putting the maximum HRT required for optimal running of BioClean technology at the minimum range of this technology. This suggests that no matter the system of anaerobic digestion partial digestion is likely to occur.

Partial digestion is likely to change the removal rates of all the variables modelled. However, the modelled removal of COD is predicted to reduce the efficiency of EBNR in the SBR. Therefore, the reduction of removal in the anaerobic digester may not actually reduce the overall removal rate by BioClean technology.

4.7.2 Sequencing Batch Reactor

The removal of phosphorus from the liquid fraction occurs with a simultaneous increase of phosphorus in the solids fraction. Therefore, the phosphorus is not lost from the system completely just moved to the solids fraction. This results in a high phosphorus content solid fraction which can be applied to land or incorporated when regrassing or cropping. It would be recommended that this be incorporated at this stage as the crop will have a higher phosphorus requirement as it grows and be able to utilise the P applied. This insures the maximised utilisation of the P. However, the solid fraction does not have the same increase in nitrogen as phosphorus. This is because during nitrification/denitrification nitrogen is released as gas which is a loss from the system. Being able to reuse the nitrogen captured as FDE to aid in the growth of pastures is a benefit of land application, as the nitrogen in FDE is sourced from the pastures so for the nitrogen that is utilised this creates a cycle. Removing nitrogen from the FDE as gas removed its potential for recycling. This will result in an increased requirement for nitrogen fertiliser as the pasture growth due to recycled nitrogen (with land application of FDE) will now require another source of nitrogen.

4.7.3 Sand Filter

The sand filter achieved statistically significant ($p<0.05$) removal of all variables accept potassium ($p = 0.6$ for all scenarios). The removal of potassium in the sand filter was assumed as there were no previous studies found that had assessed potassium removal from treated FDE by sand filtration. The sand filter data used was from gravity discharge, however it may not be practical to treat the volume of SBR effluent by gravity sand filter produced each day. Pumped discharge is possible however, this requires the use of another pump which increases potential for breakdown as well as increasing cost.

4.8 Model analysis

Rainfall is not accounted for in the modelling, which would have a significant impact on the volume of effluent. There are large areas from which effluent is captured, therefore there are large areas from which rain is captured. The use of rain diversions is possible however due to the risk of error; rain diversions are rarely used. Rain diversions are most commonly used in situations where the area is not used for cattle work for extended periods, for example the dairy shed when cows are dry (in areas where standing cows off is not required or stand-off pads are used). However, due to the risk of error (forgetting to change the system from diversion to collection), some farms do not even use them then.

An example of the volume of rainfall captured by a feed pad alone; the feed pad on Komata farm is 18 m by 100 m or 1,800 m^2. The water collected from a 10 mm rainfall event is 18,000 L. Over a year 1500 mm rainfall total 2,700,000 l or 2,700 m^3 of water captured by the feed pad alone (assuming no rainfall diversion). Rainfall is also captured on the dairy shed yard and roof, as well as storage ponds and other areas of stock management (yards, stand-off pads) adding to this total.

This model does not account for the impact of cows grazing. The related benefit of removing cows from pasture is therefore not prevalent in this model. In fact, increasing the time on feed pad (and therefore reducing grazing hours) results in an increase in the volume of effluent produced. This model produces results on the concentrations and therefore the impact is not prevalent in relation to the concentrations only the volumes. Effluent from the SBR totals $27m^3$ with 2 hours on the feed pad in comparison to $20m^3$ for no feed pad (scenarios 112 and 110 respectively). This increase in effluent captured increases the requirement for treatment and therefore the size of the treatment equipment be that the ABR, SBR, flocculation tank or land area. The resulting nutrients captured in scenario 112 is greater than 110 and therefore likely to show greater losses to the environment as a total. However, the impact of grazing and the associated excreta (in particularly urine) deposition is greater than the impact of increase nutrients applied to land. Urine patches are the equivalent applying 800 to 1,000kg Urea N/ha to that patch. this high application rate is directly associated with increase leaching loss. The benefit of land application in relation to this is that the urine is captured and spread over a larger area. This reduces the loading rate and therefore the loss of N in leachate. As BioClean technology gains the benefit of this as well as the additional benefit of the change in form of nitrogen phosphorus and potassium in the treated effluent. Additional benefits include the removal of N through the production of N gas in the nitrification/denitrification.

Land application is modelled on best management practice. However, many question, how many farms are actually follow best management practice in New Zealand. There are currently audits carried out by councils and dairy companies to ensure that FDE handling meets the required standards. The compliance question is still valid as it is possible for farmers to say they are doing one thing when they are actually doing another.

In some parts of New Zealand, the dominant system of land application for farm dairy effluent is not a practical option. The West Coast of the South Island is a good example of this, where high rainfall would require storage ponds to be of impractical depth. The high rainfall impacts on the size requirement of effluent storage in two ways. Frequent rainfall means that there are longer periods (than typical for New Zealand) between soil moisture deficits to enable land application of FDE. Effluent has to therefore be stored for longer periods between applications. Additionally, the rainfall is collected by the ponds and therefore increasing rainfall increases the amount of storage required. For this reason, two pond treatment is also impractical on the West Coast. It is important to note that to increase the storage with regards to rainfall the pond depth must be increased not surface area (as increasing surface area will increase rain captured).

Anaerobic digestion efficiency data is based on studies where dairy farm effluent is digested with the primary purpose of methane production. It is unlikely that this is the most efficient utilisation of anaerobic digestion for the BioClean system. Methane produced in the digester is expected to be flared or treated so it can be safely released to the environment. The removal efficiency as a result of anaerobic digestion is therefore likely to be overestimated in this model due to incomplete anaerobic digestion.

Sequencing batch reactor efficiencies have been based on data for systems that do not have anaerobic digester pre-treatment. This could overstate the efficiency of removal variables within the SBR due to a reduction in the concentration within the influent.

Removal rates in relation to the sand filter are derived from studies where sand filters are used as secondary treatment after septic tank treatment. The resulting removal rates are expected to be similar to that of a sand filter used in the BioClean system.

4.9 Further benefits predicted

The benefit of the BioClean technology is predicted to go beyond the improvements predicted in reducing environmental impact. Predicted benefits include; social benefit, reduced labour requirement, concentration of nutrients in solids and most importantly reduced risk.

4.9.1 Concentration of nutrients in solids

Nutrients are concentrated into the solids as solids are cycled thought the BioClean system and as a result of the biological processes that occur in the anaerobic digester and the sequencing batch reactor. By concentrating the nutrients in a solid you are effectively creating a new fertiliser product. The solids content that is practically achievable with this system is unknown, however if a 'dry' product can be achieved this would increase the potential for application in many situations. Current application of FDE to land can be restricted by soil moisture deficit, slope and drainage potential /soil structure). If the product was a solid, the application of the product would be only restricted as with current solid fertilisers. It could be applied to land with much greater slope. In relation to soil water and soil structure, its solid form means that it would be more able to be applied to moist soils or to poorly drained soils due to time taken for break down.

BioClean reduces the volume of solids in comparison to the current on farm practices. This is due to an increase in the total solids content of the solids. This is enabled through both the treatment process and also the use of a partitioned weeping wall. A reduction in the storage requirements of solids, reduces the frequency at which they need to be applied or the size of the storage bunker (weeping wall solids store).

The benefit of increased concentration of solids can be enhanced by utilising the process composting. However, the practical ability of composting has not been investigated. Composting of the FDE solids would be expected to reduce the volume of solids and change the form of nutrients. This change is typically to a more plant available form, making the nutrients more readily available. The impact of compost on soil has been widely studied however the comparison between treated FDE solids and compost is yet to be studied. It is expected that the impact of composting the solids would have a positive impact, however the significance of that benefit would require further analysis.

4.9.2 Reduction in labour requirement

When compared to the most commonly used land application system there is predicted to be a reduction in labour required to operate BioClean. BioClean is predicted to only require labour for monitoring performance and for maintenance aside from the handling of solids. As solids separation is assumed to be already in place this is not an addition to current practice. With land application there is a daily requirement for moving travelling irrigators which is not required by BioClean. This can be a laborious task and as with all manual task has the risk of human error.

4.9.3 Social benefit

BioClean is predicted to have a social benefit due to being an organic treatment system, derived from the socially accepted technology used for wastewater treatment. Currently public perception of the agricultural industry and in particular the dairy industry is poor. Promotion of new technology being developed to reduce the risk of error in the handling of FDE is predicted to have a positive impact on the dairy industries social image. This technology is organic, which is widely viewed as a positive publicly, which further increases the social benefit.

On farm the social environment is expected to improve as there is predicted to be less labour requirement for effluent, the reduction in risk is predicted to reduce the stress of farmers and therefore improve mental wellbeing. Lower labour requirements are not expected to reduce the overall farm requirement for labour units but reduce the pressure on the current farm staff by reducing daily tasks.

Reduction of stress is a massive factor of the potential benefits of this system. There is currently a growing awareness of mental wellbeing on farms across New Zealand. The most beneficial time of the year that BioClean will reduce risk is during wet periods such as winter and spring. Late winter and spring are calving season (spring calving) where stress is generally the highest for farmers. Mitigating one area of stress during this period is expected to result in improve mental wellbeing. This will have a flow on effect year-round. Improved mental wellbeing and reduced stress have been shown to be associated with an improvement in work performance (Rose, Jones et al. 1998).

Chapter 5. Economic Analysis

The following economic analysis found that over a period of 12 years there is no benefit. The cost of the development has been budgeted to be covered entirely by a loan. The loan increases the loan interest and repayments by more than costs are reduced by the use of less electricity. Investment in BioClean technology, although no financial return is made, is shown in Table 53 to be a potentially viable option for a typical 400 cow dairy farm.

5.1 Investment analysis

To enable analysis of the impact of investing in BioClean technology, an initial or ‘current’ situation has been created. The current situation is based on a typical 400 cow dairy farm in the Waikato with land application for FDE treatment. This has been compared with the budgeted or predicted impact of BioClean technology.

Table 49 shows a breakdown of the capital costs for the BioClean system. The development budget has been based on the assumption that there is already a solids separation system (weeping wall) on the farm. The main cost for the development of a BioClean system is the installation cost ($60,000). Followed by the cost of the anaerobic digestion ($36,800) and the sequencing batch reactor ($13,979). The cost of the anaerobic digester is budgeted to be $90 per cow. The cost of the sequencing batch reactor is broken down in Table 50. The cost of installation has been over budget to cover the cost of contractors and unexpected costs.

Table 49: Development budget for BioClean system

DEVELOPMENT BUDGET FOR 400 cow farm		
excl. GST		
Item	Cost	
Weeping wall catch	$	15,000.00
Separator	ASSUMED ALREADY IN	
30,000l SUMP 2	$	4,170.00
Effluent pump 1	$	1,947.00
AD	$	36,800.00
Effluent pump 2	$	1,947.00
SBR	$	13,979.91
Clarifier	$	3,951.99
Filter	$	3,000.00
Disinfection	$	3,886.26
Pipe	$	423.99
Earthworks	$	1,600.00
Electrical	$	6,800.00
Contingency	$	10,000.00
Sub total	$	103,506.15
Installation cost	$	60,000.00
Total	$	163,506.15

Table 50: SBR cost breakdown

SBR cost breakdown	
TANK	3951.99
Aerator	1199.92
Stirrer motorised	3000
Motorised valves	828
OTHER	5000
	13979.91

Daily running costs for BioClean have been broken down in Table 51 and compared to the daily running costs of land application (labelled current). This is shows that the running costs of BioClean are expected to be lower than land application. This is due to the fact that even though BioClean has two pumps and a stirrer requiring power, the effluent pump required for land application is much larger and therefore draws more power to run than all of the components of BioClean. This is due to the BioClean system pumping after the solid separation system (a product much closer to water). These pumps also pump across a smaller distance and the head (height) they are pumping is the restriction for their size.

Within the BioClean technology is solar panels which will power the electric valves and aeration. With the recent gains in solar energy generation it is now economically viable to mitigate some electrical costs with solar panels. Due to drawing larger amounts of power the stirrer and pumps have not been budgeted to be powered by solar panels. This would be possible in some locations around New Zealand with increased sunlight hours.

Table 51: Breakdown of electricity cost for Land application vs BioClean.

Daily electricity					
Current	15kw	3hrs/day ave			
	45kwh/day				
45	22.2	c/kw			
999	c				
$ 9.99				$2,707.29	/yr
New					
Pumps	1.5kw*2	@3hrs/day			
	9				
Stirrer	0.75	@12hrs/day			
	9				
	18	kwh/day			
	22.2	c/kw			
	399.6	c			
	$ 4.00			$1,082.92	/yr
		DIFFERENCE per year		$1,624.37	/yr

The cost of technology similar to BioClean is generally perceived to be costly to run. However, this has been combatted by the use of solar power for low energy use parts such as the aerator and electrical valves.

It is important to note that this analysis is based on a real situation but it still and estimation of the ‘current situation’ (land application) as data has been manipulated to match the desired scenario. The budgeted expense of BioClean, is a rough guide and a contingency has been added for the unexpected expenses. There is still chance that the cost has been underestimated.

The additional expense of interest and principle repayments on the loan used to cover the cost of development (Table 53 and Table 56), exceeds the benefit of the reduced cost of electricity. Positive annual cash surpluses are maintained despite this fact, suggesting that the investment is viable.

The current situation has been estimated to make a real cash surplus of $102,696, only slightly higher than that expected from the ‘with BioClean’ situation of $98,097. This shows that even with 100% debt funding the impact of this investment to the bottom line is minimal.

Table 52: Investment analysis of 'current' situation.

Existing Situation																
	Production Assumption			Units	Price/kgms	Income		Total Land Assests				Buildings	Vehicles	Livestock Values		Plant and Machinery
	Milksolids			152,400	$ 6.45	982,980		138	5,163,862			680,000	104,000	MA Cows	433,920	180,000
	Dividends fonterra					30,480								R1 Heifers	50,880	
	Cattle Sales					73,758								R2 Heifers	86,160	
	Rebates					2,800										
	Other income					15,671			Expenses	-840,000	100%		Shares			
					TOTAL	$1,105,689	100%						498,348		Total Assets	
					TOTAL/kgms	7.26									7,197,170	
					Income%	1%										
					Tax	-28%										
					Inflation	2%										
					Capital Gain	5%										

Assets	Year0	1		2		3		4		5		6	
Income Adjustment		100%		100%		100%		100%		100%		90%	
Expenses Adjustment		100%		100%		100%		100%		100%		110%	
		Cash	Tax	Cash	Tax	Cash	Tax	Cash	Tax	Cash	Tax	Cash	Tax
Farmsize	-5,163,862												
Shares	-498,348												
MA Cows	-433,920												
R1 Heifers	-50,880												
R2 Heifers	-86,160												
Buildings	-680,000												
Vehicles	-104,000												
Plant and Mach	-180,000												
Exisiting Loan	2,544,899												
Interest		-122,835	-122,835	-122,408	-122,408	-121,963	-121,963	-121,499	-121,499	-121,015	-121,015	-120,510	-120,510
Principle		-10,009		-10,436		-10,881		-11,345		-11,829		-12,334	
Depreciation			-57,280		-50,288		-44,335		-39,263		-34,936		-31,241
Income		1,116,746	1,116,746	1,127,913	1,127,913	1,139,192	1,139,192	1,150,584	1,150,584	1,162,090	1,162,090	1,056,340	1,056,340
Expenses		-856,800	-856,800	-873,936	-873,936	-891,415	-891,415	-909,243	-909,243	-927,428	-927,428	-1,040,574	-1,040,574
Losses Carried Forward					0		0		0		0		0
Taxable Income			79,831		81,282		81,480		80,580		78,712		-135,985
Tax Paid		-22,353	-22,353	-22,759	-22,759	-22,814	-22,814	-22,562	-22,562	-22,039	-22,039	0	38,076
Nominal Cash F	-4,652,271	104,749		98,375		92,120		85,935		79,779		-117,078	
Real Cash Flow	-4,652,271	102,696		94,555		86,806		79,391		72,259		-103,962	

Assets	7		8		9		10		11		12	
Income Adjustment	100%		100%		100%		100%		100%		100%	
Expenses Adjustment	100%		100%		100%		100%		100%		100%	
	Cash	Tax	Cash	Tax	Cash	Tax	Cash	Tax	Cash	Tax	Cash	Tax
Farmsize											11,761,109	
Shares											632,026	
MA Cows											433,920	
R1 Heifers											50,880	
R2 Heifers											86,160	
Buildings											544,432	
Vehicles											14,855	
Plant and Mach											23,680	
Exisiting Loan											-2,066,836	
Interest	-119,983	-119,983	-119,434	-119,434	-118,862	-118,862	-118,264	-118,264	-117,641	-117,641	-116,991	-116,991
Principle	-12,860		-13,409		-13,982		-14,579		-15,202		-15,852	
Depreciation		-28,081		-25,374		-23,061		-21,054		-19,334		-17,847
Income	1,185,448	1,185,448	1,197,303	1,197,303	1,209,276	1,209,276	1,221,368	1,221,368	1,233,582	1,233,582	1,245,918	1,245,918
Expenses	-964,896	-964,896	-984,194	-984,194	-1,003,878	-1,003,878	-1,023,955	-1,023,955	-1,044,434	-1,044,434	-1,065,323	-1,065,323
Losses Carried Forward		-135,985		-63,497		0		0		0		0
Taxable Income		-63,497		4,804		63,485		58,095		52,173		45,756
Tax Paid	0	17,779	-1,345	-1,345	-17,776	-17,776	-16,266	-16,266	-14,608	-14,608	-12,812	-12,812
Nominal Cash F	87,709		78,920		54,778		48,303		41,696		11,515,166	
Real Cash Flow	76,356		67,357		45,836		39,625		33,534		9,079,629	

	NPV			IRR	
Discount Rates	Nominal	Real		Real	Nominal
2%	9,674,085	3,048,588		6.62%	8.76%
4%	7,734,932	1,515,267			
6.9%	5,648,683	-135,185			
8%	5,032,449	-622,932			
10%	4,095,266	-1,365,015			

Table 53: Investment analysis of 'with BioClean'.

Scenario 'With BioClean'																									
	Production Assumption			Current	Price/kgms	Income		Total Land Assets			Plant and Machinery		Buildings	Vehicles	Livestock Values										
	Milksolids			152,400	$ 6.45	982,980		138	5,163,862			180,000	783,506	104,000	MA Cows	433,920									
	Dividends fonterra					30,480									R1 Heifers	50,880									
	Cattle Sales					73,758									R2 Heifers	86,160									
	Rebates					2,800							Shares												
	Other income					15,671			Expenses				498,348												
					TOTAL	$ 1,105,689	100%		838,376	100%					Total Assets										
					TOTAL/kgms	7.26									7,300,676										
					Income%	1%																			
					Tax	-28%																			
					Inflation	2%																			
					Captial Gain	5%																			
Income Adjustment		100%		100%		100%		100%		100%		70%		100%		100%		100%		100%		100%		100%	
Expenses Adjustment		100%		100%		100%		100%		100%		90%		100%		100%		100%		100%		100%		100%	
Assets	Year 0	1		2		3		4		5		6		7		8		9		10		11		12	
		Cash	Tax	Cash	Tax	Cash	Tax	Cash	Tax	Cash	Tax	Cash	Tax	Cash	Tax	Cash	Tax	Cash	Tax	Cash	Tax	Cash	Tax	Cash	Tax
Farmsize	-5,163,862																							11,761,109	
Shares	-498,348																							632,026	
MA Cows	-433,920																							433,920	
R1 Heifers	-50,880																							50,880	
R2 Heifers	-86,160																							86,160	
Buildings	-783,506																							544,432	
Vehicles	-104,000																							14,855	
Plant and Mach	-180,000																							23,680	
2,708,405																									
New Loan	163,506																							311,175	
Exisiting Loan	2,544,899																							2,066,836	
Interest		-129,457	-129,457	-128,809	-128,809	-128,134	-128,134	-127,430	-127,430	-126,697	-126,697	-125,932	-125,932	-125,136	-125,136	-124,306	-124,306	-123,441	-123,441	-122,540	-122,540	-121,601	-121,601	-120,622	-120,622
Principle		-15,471		-16,119		-16,794		-17,498		-18,231		-18,996		-19,792		-20,622		-21,487		-22,388		-23,327		-24,306	
Depreciation			-72,806		-63,485		-55,552		-48,797		-43,041		-38,130		-33,936		-30,351		-27,282		-24,650		-22,390		-20,445
Income		1,116,746	1,116,746	1,127,913	1,127,913	1,139,192	1,139,192	1,150,584	1,150,584	1,162,090	1,162,090	821,598	821,598	1,185,448	1,185,448	1,197,303	1,197,303	1,209,276	1,209,276	1,221,368	1,221,368	1,233,582	1,233,582	1,245,918	1,245,918
Expenses		-855,143	-855,143	-872,246	-872,246	-889,691	-889,691	-907,485	-907,485	-925,634	-925,634	-849,732	-849,732	-963,030	-963,030	-982,291	-982,291	-1,001,936	-1,001,936	-1,021,975	-1,021,975	-1,042,415	-1,042,415	-1,063,263	-1,063,263
Losses Carried Forward					0		0		0		0		0		-192,197		-128,851		-68,497		-11,881		0		0
Taxable Income			59,340		63,374		65,815		66,872		66,718		-192,197		-128,851		-68,497		-11,881		40,322		47,176		41,587
Tax Paid		-16,615	-16,615	-17,745	-17,745	-18,428	-18,428	-18,724	-18,724	-18,681	-18,681	0	53,815	0	36,078	0	19,179	0	3,327	-11,290	-11,290	-13,209	-13,209	-11,644	-11,644
Nominal Cash F	-4,592,271	100,059		92,995		86,145		79,447		72,846		-173,063		77,490		70,084		62,411		43,175		33,030		15,951,156	
Real Cash Flow	-4,592,271	98,097		89,383		81,176		73,397		65,979		-153,675		67,460		59,816		52,223		35,419		26,565		12,577,378	
NPV Post Finance and Tax				IRR Post Finance and Tax																					
Discount Rates	Nominal	Real		Real	Nominal																				
2%	8,480,948	5,778,493		9.46%	11.7%																				
4%	5,825,127	3,681,016																							
6.92%	2,957,489	1,415,577																							
8%	2,130,293	761,897																							
9.46%	1,166,353	0																							
10%	851,756	-248,702																							
12%	-159,809	-1,048,575																							
Marginal Return																									
Nominal	-600,000	-4,690		-5,380		-5,975		-6,488		-6,933		-55,985		-10,219		-8,836		7,633		-5,128		-8,666		4,435,990	
Real	-600,000	-4,598		-5,171		-5,630		-5,994		-6,279		-49,713		-8,896		-7,542		6,387		-4,207		-6,969		3,497,748	
	NPV			IRR																					
Discount Rate	Real	Nominal		Real	Nominal																				
2%	2,069,906	2,799,136		15.1%	17.4%																				
4%	1,506,750	2,082,469																							
6%	1,067,233	1,525,285																							
8%	724,829	1,090,118																							

5.2 NPV's and IRR's

The weighted average cost of capital for the addition of BioClean technology has been calculated to be 4.92%. The addition of 2% for risk (industry and market risk) and 0% for personal factor gives a discount rate of 6.92% shown in Table 53, with a real net present value (NPV) of $1,415,577. This shows that even with the addition of BioClean technology and its associated cost, over 12-year life (of this investment analysis) it is estimated that returns will meet and surpass goals. The real internal rate of return (IRR) after finance and tax of 9.46% shows the discount rate at which NPV becomes zero. The higher the IRR the better as it represents a higher predicted return on investment for the life of the analysis (in this case 12 years).

Table 54: Post Finance and Tax NPV's for the addition of BioClean scenario.

NPV Post Finance and Tax		
Discount Rates	Nominal	Real
2%	8,480,948	5,778,493
4%	5,825,127	3,681,016
6.92%	2,957,489	1,415,577
8%	2,130,293	761,897
9.46%	1,166,353	0
10%	851,756	-248,702
12%	-159,809	-1,048,575

Table 55: Post Finance and Tax IRR's.

IRR Post Finance and Tax	
Real	Nominal
9.46%	11.7%

The NPV and IRR values for the scenario in which BioClean has been installed on farm show that the expense has been easily absorbed by the business. The farm is predicted to maintain a cash surplus for the year throughout the life of the investment analysis. In year 6 a 'hard' year was simulated by increasing the expenses and reducing income, representing an event such as a drought. This was the event in which net cash deficit was budgeted (Table 52). The cost of BioClean is therefore predicted to be able to be absorbed by a dairy farm with 400 cows.

Investing in BioClean would therefore be predicted to be a viable option for farmers assuming that it can achieve treatment standards significantly higher than that of technology like ClearTech. If this is not achieved by BioClean then the marginal benefit of the organic process over the chemical process is likely to be outweighed by the increased cost of capital and for installation. The BioClean process is a more complex process which involves more parts. More parts lead to increased cost of maintenance and increased risk of failure these factors would also contribute to the reduced marginal benefit of organically treating FDE.

5.3 Secondary Economic effects

Technology such as BioClean that is able to biologically treat FDE to produce a clearwater and treated solid effluent will enable the dairy industry to maintain the benefit that it receives from the ‘Clean and Green’ image of New Zealand. This image gives New Zealand products a marginal benefit over others on the international market and therefore enables New Zealand to maintain a slight competitive advantage. This benefit is particularly prevalent in markets such as China. China is a great example of an emerging middle class. This increases the demand for higher value products and means consumers have increased disposable incomes and therefore increased potential to demand things such as environmentally friend products. As these markets continue to increase and develop it is important that New Zealand maintains is position ahead of the game to enable the maintenance of competitive advantage. BioClean is technology that has the potential to enable New Zealand to maintain its ‘Clean and green’ image.

Chapter 6. Limitations

6.1 Nutrient removal modelling

The ability to assess the effect of a treatment method such as two pond treatment or ClearTech may be limited by available data. For each treatment method data will be collected differently at different time periods and cover different parameters. The previously completed studies do not have all of the parameters investigated in this study, therefore the use of combining information from different studies is required. Each study is undertaken in different conditions and therefore the numbers are not all comparable. Utilising the wide range of data available, it is possible for the most part to create a model which is representative. As with all statistical models, there is an element of error. This model is unable to account for all variations that occur and to reduce the chance of error, averages have been used where possible. Some generalisations have been made, for example the use of only two different soil drainage types for the assessment of the performance land application. When realistically there are many factors and different processes within a soil which affect the ability of it to treat and absorb the effects of effluent application. This generalisation has been made to give a general overview that is representative, and to increase the amount of data available to use to drive the model.

The model created is more accurate for some variables than others and more accurate overall for some methods of treatment than others. The accuracy depends on the availability of the data and the number of influencing factors. The ClearTech model is most likely the most robust, as the data is all sourced from one recent study. No modification of the data was required to fit the data to the model and there are few external factors that impact the performance of its technology. ClearTech is not a biological process unlike the other treatment systems, this is why it can be much more accurately modelled. In saying this the model outputs for all variables are informative in terms of nutrient concentration and percentage change that occurs throughout the system.

BioClean is the least accurately modelled system. This is obvious as it is a combination of technology that haven’t been used together for this purpose before and therefore many assumptions and estimations must be made. The main source of error in this model is the way in which the performance of BioClean is calculated. The first phase modelled is, anaerobic digestion. The data from this simulation, with its standard deviation of 10% is used as the input for the second stage of treatment (EBNR SBR). The performance of which was again simulated with a standard deviation for the change percentage of 10%. This occurred a third time for the sand filter and *E. coli* was simulated a fourth time for the UV disinfection impact. Each time the data is simulated the potential for error increases. The result for this model is potentially due to a large variation in the residual content of the treated FDE of each parameter, which was clear in the *E. coli* data.

6.2 Excel limitations

6.2.1 Random number generator

Excel random number generator does not create truly random numbers. The RAND function, as used in the model created in this study, creates pseudorandom numbers. It uses Mersenne Twister, which is the most broadly used all-purpose pseudorandom number generator. It does not derive truly random numbers. The sequence of numbers created is not repeatable and therefore deemed suitable for the purpose of this experiment. It is important to note that excel 2019 was used to create this model.

6.2.2 Data tables

In the Monte Carlo simulation data tables were formed for each scenario to simulate a data population. For each variable 10,000 numbers were generated. The reliability of the mean of the data generated increases with the size of the data table. Initially data tables were planned to generate a population of 20,000 values for each variable. However, the capacity of excel inhibited the formation of such data tables. Therefore, the number of values generated in the data tables had to be reduced and therefore it can be assumed that the data presented was also reduced.

6.3 Other limitations

This system models the performance of BioClean based on the assumption that the anaerobic digester and sequencing batch reactor are running to full capacity. However, biological treatment technology such as BioClean has a ‘start up period’ where the efficiency of the system runs at below capacity due to the initial requirement to build up activated sludge. Dairy farms across New Zealand run predominantly a spring calving season. This results in a period of ‘shut-down’ for 2 months over calving where cows are not in milk. During this period many farms across New Zealand do not capture FDE. Cows are either kept on the paddocks or (particularly in the South Island of New Zealand) sent off farm for winter grazing. Where this occurs the BioClean system will be shut-down during this period as there would be no feed source for the bacteria. As the cows start calving and FDE returns to being captured the BioClean system would be started up again. The gradual nature of the return to FDE capture at the start of calving season lends itself well to the start up of the BioClean system. A lower volume of FDE would be required to be processed and therefore if insufficient treatment occurred it could be recycled around to ensure treatment levels are maintained. The temperature during calving season would however be restrictive of efficient operation of both the AD and SBR. Once running, both the anaerobic digester and sequencing batch reactor maintain the heat required due to the biological activity. However, that source of heat is not there at the start so if the start up period were to be during the winter or early spring, then heat would be required to ensure the biological activity starts to accelerate.

There are many dairy farms in New Zealand that would not experience a ‘shut-down’ period, as the cows are retained on farm and infrastructure such as stand-off pads and feed pads remain in use. For these farm systems the operation of BioClean technology would be maintained year-round. This mitigates the issue of starting the BioClean system during the cold period. If started during the summer the temperature is likely to be sufficient to enable biological activity. The BioClean system could be started up during the summer period and used in conjunction with the existing Land Application system until the required treatment standard is achieved.

Chapter 7. Conclusions and Recommendations

The results of this model show performance that is not sufficient for the proposed purpose of BioClean. The resulting data would only provide a liquid green wash and treated solid as ClearTech does. The main difference being that it is an organic process and therefore there is not added environmental impact of residual chemicals added. However, the aim of this study was to assess the potential of this product to ‘replace’ land application as a method of FDE treatment. Although BioClean would utilise land application for the management of treated solids, the proposed study was to ‘clean’ the liquid fraction to a standard that would allow discharge to waterways as a minimum and at best recycling of the water for stock water use, and hand held hoses. This level of ‘cleaning’ has not been achieved. However, this is only a model simulation and there are many limitations to the accuracy of the data. the results of this model show that the performance of BioClean is far below where it would be required for discharge to waterways. The main benefit BioClean showed in this model was the removal of Nitrogen.

The next stage of the development process would be to run a lab scale experiment to simulate the modelled EBNR AD/SBR system. This will enable confirmation of the model and improvement of the system to maximise ‘cleaning’ of the liquid fraction. To maximise the benefit of the lab-scale experiment it would be recommended that further study to assess the potential for the improving the performance of BioClean from its modelled performance to ensure it can meet standards required. Once running the lab-scale experiment it would be important to assess the impact of the modelled variables (washdown system, feed combination, solids separation) and continuously monitor the fluctuations within the treatment system. This will allow enhanced understandings of the biological action taking place and therefore enable optimisation of the process to maximise its performance. Variables to monitor would be;

- Impact of influent volume on performance
    - Overall volume
    - Concentration of nutrients (dilution factor)
- Assess HRT of AD – how to make it efficient at 1 – 2 days

- Test options for two phase EBPR so that N removal can be enhanced in the SBR and P removal is started in AD,
    - AD then SBR with anoxic, aerated, anoxic aerated draw, idle, fill phases, for promotion of N and P removal and then addition of O_2 to increase DO levels for discharge of treated effluent to waterways.

The development of the model, to improve the accuracy of its results would enable farmers to utilise it to identify the most effective method for the treatment of FDE for their farming system. To allow more accurate predictions of the treatment efficiency of each method with differing farms systems more variables would need to be added. Factors already accounted for such as diet and time spent in capture areas would need to be improved to more accurately represent the data. Other factors such as increased variables relating to the efficiency of land application. Potentially moving it away from assuming best practice and allowing it to simulate actual performance. Also including the impact of the BioClean solids to land to give a representation of overall benefit.

7.1 Implications for full-scale BioClean treatment of farm dairy effluent

The next stage of process development would be to conduct a lab scale trial of the BioClean FDE treatment process. Further research into the operating conditions of the AD and SBR would be required to ensure that the process is optimised for its purpose. Further assessment of the potential for 2 stage phosphorus removal with the second phase operating simultaneously with nitrogen removal.

Sequencing batch reactors operated for enhanced biological nutrient removal typically operate with an anaerobic phase, as the influent has already been anaerobically pre-treated this step may not be needed. If the influent entered below the sludge blanket this would enable enhanced mixing of the pre-treated FDE with the activated sludge in an anoxic environment. This would be followed by an aerobic phase then anoxic and finally aerobic. The nitrate which is typically formed in the first stage within the SBR will be present in the influent so during the first anoxic stage, it can be denitrified. The first aerobic phase is then important to be of sufficient length that complete nitrification and phosphorus uptake occur. In the final anoxic phase is where the final denitrification occurs as well as potentially some further uptake of phosphorus but anaerobically active PAOs. The final aerobic stage is shorter than the first and is for polishing. It returns the oxygen content (increase DO), which drives off any gasses such as N_2.

7.1.1 Predicted market

This technology is predicted to be marketed to;

- High rainfall areas
- Farms with poorly drained soils,
- Farms with low WHC soils
- Rolling to steep farms
- Farms with hump and hollow contouring
- Peat farms
- Organic farmers
- West coast farms

This technology is expected to be in demand from farmers who are currently on the verge of compliance or non-compliant. The West Coast of the South Island (due to rainfall) and Hauraki Plains (peat) are also predicted to be large markets.

7.2 Objectives in review

A system that may potentially treat FDE biologically to produce a clearwater and treated solid effluent has been identified. BioClean biologically treats FDE to produce a treated solid. However, the liquid fraction is not predicted to meet the standards for a clearwater. This technology was found to be economically viable if, and only if it was to achieve the removal standards required. If BioClean cannot achieve a clearwater liquid fraction, then the benefit gained from its use over technology such as ClearTech would not surpass the increased capital expense of installation in many cases.

Chapter 8. References

Aislabie, J., et al. (2001). "Leaching of bacterial indicators of faecal contamination through four New Zealand soils." Soil Research **39**(6): 1397-1406.

Akbarzadeh, A., et al. (2012). "Optimization of SBR system for enhanced biological phosphorus and nitrogen removal." International Journal of Environmental Health Engineering **1**: 49.

Alibaba.com. "Ultraviolet UV Light Sterilizer for Water Treatment ". Retrieved 10/09/2019, from https://www.alibaba.com/product-detail/Ultraviolet-UV-Light-Sterilizer-for-Water_60592935193.html.

Andrew van Bunnik, A. P., Eleanor Somerset,, et al. (2007). Environment New Zealand 2007. Wellington, New Zealand, Ministry for the Environment.

Ausseil, O. and M. Clark (2007). Recommended Water Quality Standards for the Manawatu-Wanganui Region: Technical Report to Support Policy Development.

Bachmann, A., et al. (1985). "Performance characteristics of the anaerobic baffled reactor." Water Research **19**(1): 99-106.

Bernet, N. and F. Béline (2009). "Challenges and innovations on biological treatment of livestock effluents." Bioresource Technology **100**(22): 5431-5436.

Bolzonella, D., et al. (2002). "Biological nutrient removal wastewater treatments and sewage sludge anaerobic mesophilic digestion performances." Water science and technology : a journal of the International Association on Water Pollution Research **46**: 199-208.

Bortone, G., et al. (1992). "Nitrification, Denitrification and Biological Phosphate Removal in Sequencing Batch Reactors Treating Piggery Wastewater." Water Science and Technology **26**(5-6): 977-985.

Broughton, A. D. (2009). Hydrolysis and Acidogenesis of Farm Dairy Effluent for Biogas Production at Ambient Temperatures. Engineering. Massey University, Massey University. **Master of Engineering in Environmental Engineering:** 140.

Cameron, K. and H. Di (2019). "A new method to treat farm dairy effluent to produce clarified water for recycling and to reduce environmental risks from the land application of effluent." Journal of Soils and Sediments.

Clearpond New Zealand. "Solarfree Solar Pump (Various Sizes)." Retrieved 10/09/2019, from https://www.clearpond.co.nz/shop/water-garden/submersible-pumps-accessories/oase-aquarius-fountain-water-feature-pumps/solarfree-solar-pump/.

DairyNZ (2012). Farmfact; Effluent solids separation using a mechanical system (6-27), DairyNZ.

DairyNZ (2012). Farmfact; Passive systems for effluent solids separation (6-26), DairyNZ.

DairyNZ (2018). QuickStats about dairy - New Zealand. DairyNZ.

DairyNZ (2019). Facts and Figures - A quick reference guide from New Zealand dairy farmers. www.dairynz.co.nz, DairyNZ.

Drinan, J. E. and F. R. Spellman (2012). Water and Wastewater Treatment. United States of America, CRC Press.

Farmsource. "Store." Retrieved 09/09/2019, from https://store.nzfarmsource.co.nz/.

Heubeck, S., et al. (2014). Variability of Effluent Quality and Quantity on Dairy Farms in New Zealand. Hamilton, NZ, National Institute of Water and Atmospheric Research Ltd (NIWA).

Hickey, C. W., et al. (1989). "Effluent characteristics of dairy shed oxidation ponds and their potential impacts on rivers." New Zealand Journal of Marine and Freshwater Research **23**(4): 569-584.

Horizons Regional Council. (2014). One Plan.

Houlbrooke, D. J., et al. (2011). Matching farm dairy effluent storage requirements and management practices to soil and landscape features. Hamilton, Landcare Research.

Jantrania, A. R. and M. A. Gross (2006). Advanced onsite wastewater technologies. United States of America, CRC Press.

Keller, J., et al. (2001). "Full-scale demonstration of biological nutrient removal in a single tank SBR process." Water Science and Technology; **43**(3): 355-362.

Kirk Irrigation (n.d.). "Solids Separators." Retrieved 17/2/2019, from www.kirkirrigation.co.nz/solids-separators.

Longhurst, R. D., et al. (2017). Nutrient content of liquid and soild effluents on NZ dairy cow farms. Science and policy: nutrient management challenges for the next generation. L. D. Currie and M. J. Hedley. Palmerston North, New Zealand, Fertiliser and Lime Research Center, Massey University,. **Occasional Report No. 30**.

Longhurst, R. D., et al. (2000). "Farm dairy effluent: A review of published data on chemical and physical characteristics in New Zealand." New Zealand Journal of Agricultural Research **43**(1): 7-14.

Manderson, T. (2014). Pahiatua Waste Water Treatment Plant: Discharge of Treated Wastewater. S. Cook, Opus International Consultants Ltd.

McLeod, M., et al. (2003). "Microbial and chemical tracer movement through two Southland soils, New Zealand." Soil Research **41**(6): 1163-1169.

Mendes, W. d. C., et al. (2016). "Potassium leaching in different soils as a function of irrigation depths." Revista Brasileira de Engenharia Agrícola e Ambiental **20**: 972-977.

Meyer, D., et al. (2007). "Particle Size and Nutrient Distribution in Fresh Dairy Manure." Applied Engineering in Agriculture **23**: 113-118.

Michael H, G. (2002). The Wastewater Nitrogen Cycle. Nitrification and Denitrification in the Activated Sludge Process, John Wiley & Sons, Inc.

Moser, M. A., et al. (2014). Benefits, Costs and Operating Experience at Seven New Agricutural Anaerobic Digesters

New Zealand Government 1991 Resource Management Act. Author. Wellington, New Zealand.

New Zealand Government 2019 (2019). Draft National Policy Statement for Freshwater Management. M. f. t. Environment.

Nishio, N. and Y. Nakashimada (2013). Chapter 7 - Manufacture of Biogas and Fertilizer from Solid Food Wastes by Means of Anaerobic Digestion. Food Industry Wastes. M. R. Kosseva and C. Webb. San Diego, Academic Press**:** 121-133.

Obaja, D., et al. (2003). "Nitrification, denitrification and biological phosphorus removal in piggery wastewater using a sequencing batch reactor." Bioresource Technology **87**(1): 103-111.

Oehmen, A., et al. (2007). "Advances in enhanced biological phosphorus removal: From micro to macro scale." Water Research **41**(11): 2271-2300.

R.J. Craggs, C. C. T., J.P.S. Sukias and R.J. Davies-Colley (2003). "Dairy farm wastewater treatment by an advanced pond

system." Water Science and Technology; **48**(2): 291-297.

Roach, C. G., et al. (2001). Land application of farm dairy effluent for sustainable dairy farming. New Zealand Grassland Association.

Rose, J., et al. (1998). "The impact of a stress management programme on staff well-being and performance at work." Work & Stress **12**(2): 112-124.

Samer, M. (2015). Biological and Chemical Wastewater Treatment Processes**:** 1-50.

Smith, V. H., et al. (1999). "Eutrophication: impacts of excess nutrient inputs on freshwater, marine, and terrestrial ecosystems." Environmental Pollution **100**(1): 179-196.

Staff, A. and C. A. Cotton (2008). Ultraviolet Disinfection Handbook. Denver, UNITED STATES, American Water Works Association.

Statistics New Zealand (2018). Change in livestock numbers.

Stewart, G. and R. Rout (2007). Reasonable Stock Water Requirements - Guidelines for Resource Consent Applications Horizons Regional Council.

Tie, L. and M. Sivakumar (2006). Dairy shed wastewater treatment by anaerobic digestion technology. Environment Working Together - A Multi-Disciplinary Approach: 10th Annual Environment Postgraduate Conference. Cairns, QLD Asutralia: James Cook University**:** 282-287.

Tilche, A., et al. (1999). "Biological phosphorus and nitrogen removal in a full scale sequencing batch reactor treating piggery wastewater." Water Science and Technology **40**(1): 199-206.

United States Environmental Protection Agency (1999). Watewaster Technology Fact Sheet: Intermittent Sand Filters. Washington D.C., United States Environmental Protection Agency, Office of Water.

Vanderholm, D. H. (1984). Agricultural waste manual. NZAEI project report. Lincoln New Zealand, Lincoln College. NZAEI. **32**.

Waikato Regional Council (n.d.). "Applying effluent to land." from https://www.waikatoregion.govt.nz/community/your-community/for-farmers/effluent-management/applying-effluent-to-land/.

Waikato Regional Council. (2013). Healthy Farms, Healthy Rivers NEWS. Hamilton, Waikato Regional Council.

Ward, A. J., et al. (2008). "Optimisation of the anaerobic digestion of agricultural resources." Bioresource Technology **99**(17): 7928-7940.

Wheeler, D., et al. (2012). Effluent Management in OVERSEER nutrient budgets. Hamilton, Ruakura Research Center.

White, J., & Hodgson, J. (1999). New Zealand pasture and crop science. Auckland, N.Z. ; Oxford: Oxford University Press.

Wilkie, A. (2005). Anaerobic Digestion of Dairy Manure: Design and Process Considerations. Dairy Manure Management Conference. Ithaca, NY**:** 301-312.

Chapter 9. Appendicies

9.1 Appendix 1- Horizons Regional Council

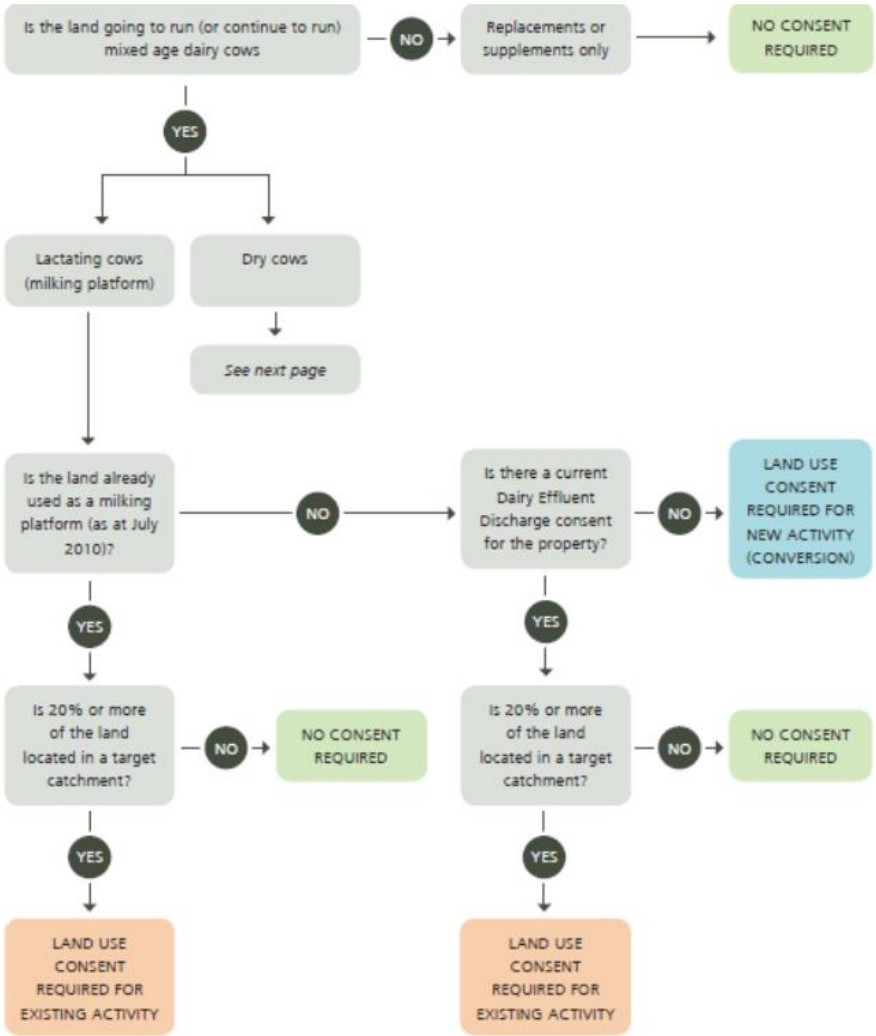

Figure 18: Horizons Regional Council 'One Plan' – Consent to farm flow diagram.

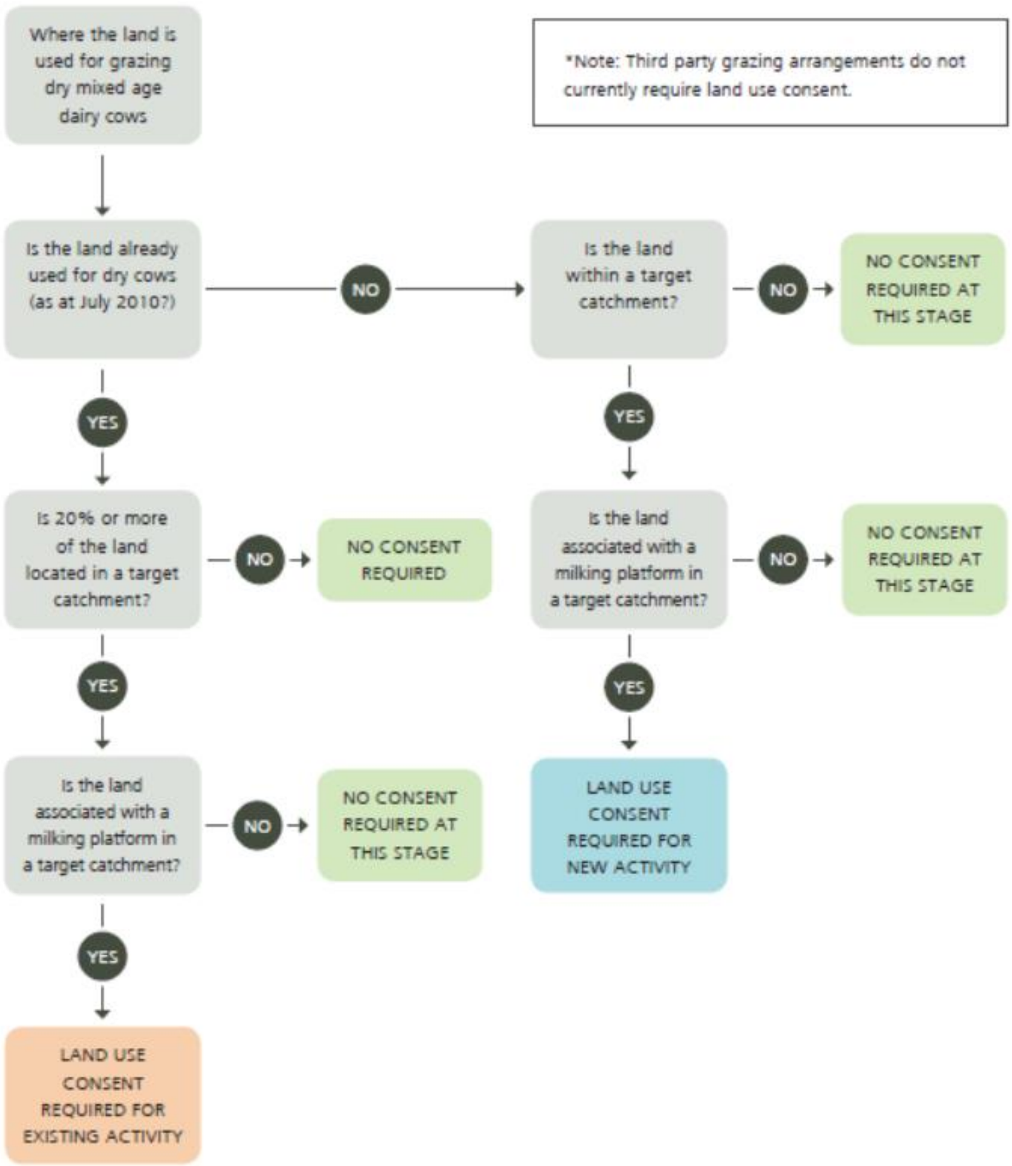

Figure 19: Horizons regional council 'One Plan' Consent for runoff flow diagram.

9.2 Appendix 2 – BioClean Results

9.2.1 Nitrogen Histograms

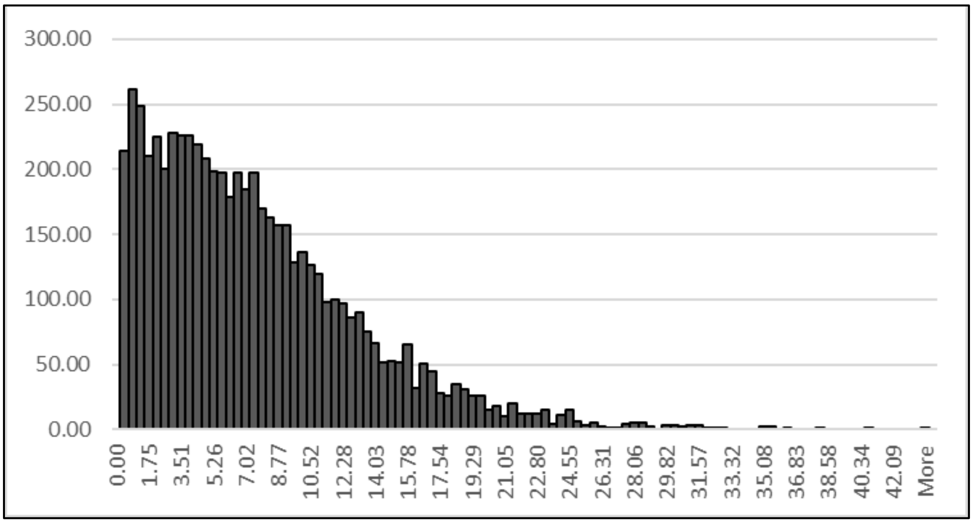

Figure 20: Scenario 110, Histogram of BioClean residual nitrogen data.

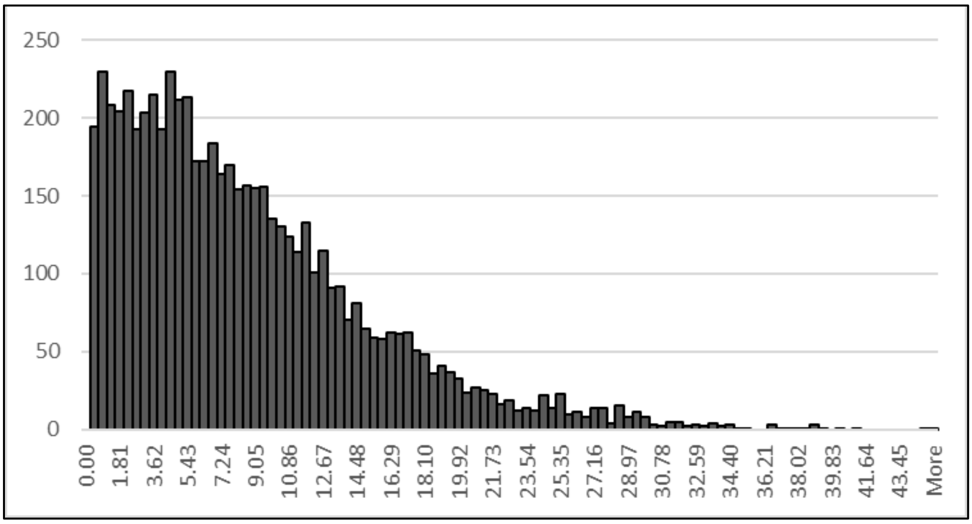

Figure 21: Scenario 118, Histogram of BioClean residual nitrogen data.

9.2.2 Phosphorus Histograms

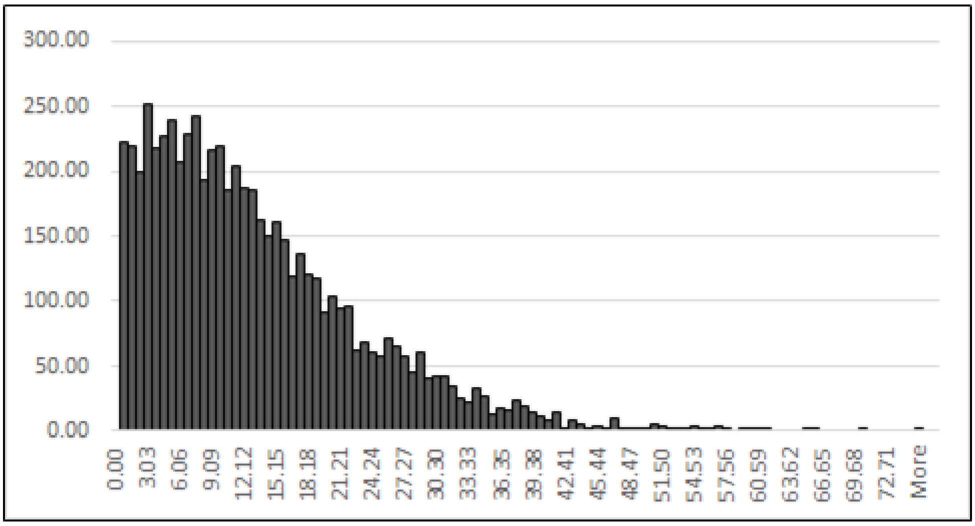

Figure 22: Scenario 114, Histogram of BioClean residual P data

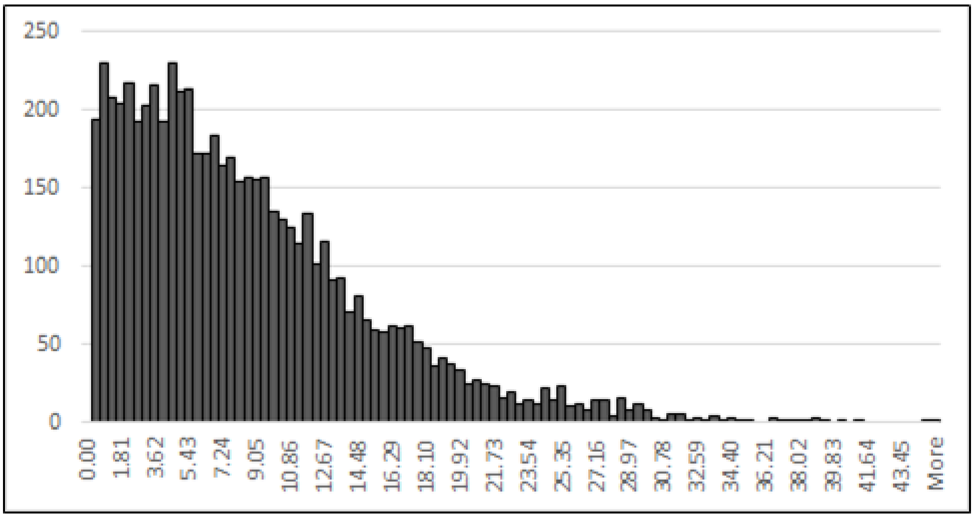

Figure 23: Scenario 118, Histogram of BioClean residual P data.

9.2.3 Potassium Histograms

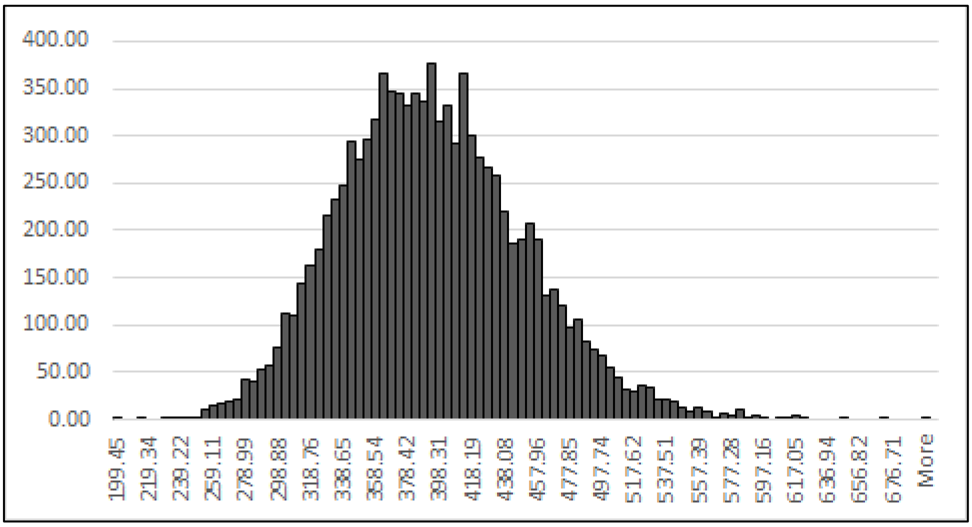

Figure 24: Scenario 110, Histogram of BioClean Residual K data.

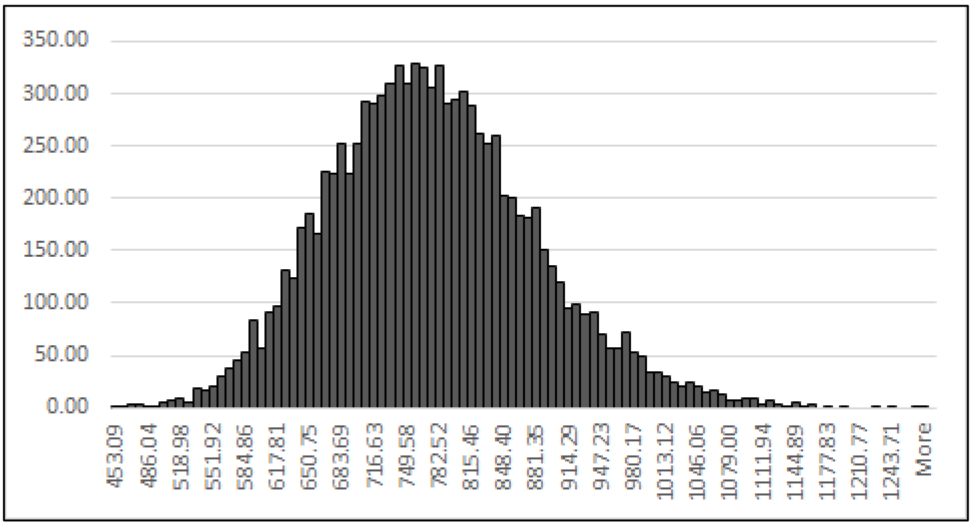

Figure 25: Scenario 94, Histogram of BioClean residual K data.

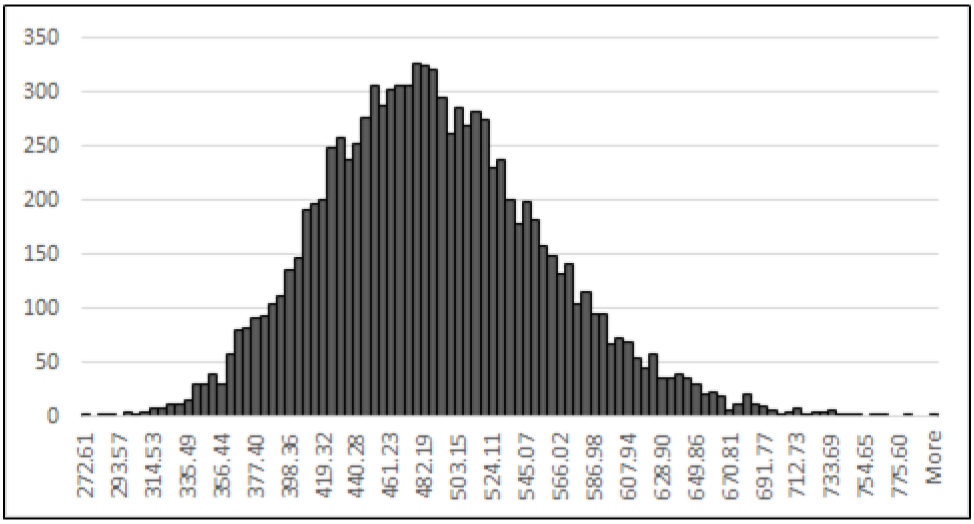

Figure 26: Scenario 544, Histogram of BioClean residual K data.

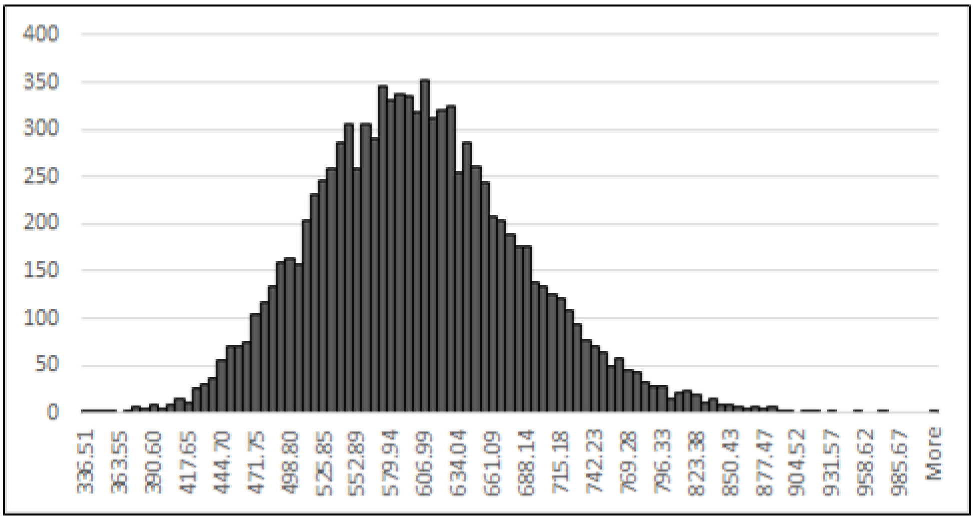

Figure 27: Scenario 328, Histogram of BioClean residual K data.

9.3 Appendix 4 – Economic analysis

Table 56: Schedule of loans, current and with BioClean.

	Land		Plant and Materials			
Loan 1	2,272,099	Loan 2	208,000	PMT	15,373	
		Term	20			
Rate	4.9%	Rate	4.05%			
Year		Opening	Principal	Interest	Closing	Check
1	111,333	208,000	6,949	8,424	201,051	15,373
2	111,333	201,051	7,230	8,143	193,821	15,373
3	111,333	193,821	7,523	7,850	186,298	15,373
4	111,333	186,298	7,828	7,545	178,470	15,373
5	111,333	178,470	8,145	7,228	170,325	15,373
6	111,333	170,325	8,475	6,898	161,851	15,373
7	111,333	161,851	8,818	6,555	153,033	15,373
8	111,333	153,033	9,175	6,198	143,858	15,373
9	111,333	143,858	9,547	5,826	134,311	15,373
10	111,333	134,311	9,933	5,440	124,378	15,373
11	111,333	124,378	10,336	5,037	114,042	15,373
12	111,333	114,042	10,754	4,619	103,288	15,373
13	111,333	103,288	11,190	4,183	92,098	15,373
14	111,333	92,098	11,643	3,730	80,456	15,373
15	111,333	80,456	12,114	3,258	68,341	15,373
16	111,333	68,341	12,605	2,768	55,736	15,373
17	111,333	55,736	13,116	2,257	42,621	15,373
18	111,333	42,621	13,647	1,726	28,974	15,373
19	111,333	28,974	14,199	1,173	14,774	15,373
20	111,333	14,774	14,774	598	0	15,373
21	111,333					
22	111,333					
23	111,333					
24	111,333					
25	111,333					

	Buildings				
	Loan 3	64,800	PMT	6,138	
	Term	15			
	Rate	4.75%			
Year	Opening	Principal	Interest	Closing	Check
1	64,800	3,060	3,078	61,740	6,138
2	61,740	3,205	2,933	58,535	6,138
3	58,535	3,358	2,780	55,177	6,138
4	55,177	3,517	2,621	51,660	6,138
5	51,660	3,684	2,454	47,976	6,138
6	47,976	3,859	2,279	44,117	6,138
7	44,117	4,042	2,096	40,075	6,138
8	40,075	4,234	1,904	35,840	6,138
9	35,840	4,436	1,702	31,405	6,138
10	31,405	4,646	1,492	26,759	6,138
11	26,759	4,867	1,271	21,892	6,138
12	21,892	5,098	1,040	16,794	6,138
13	16,794	5,340	798	11,453	6,138
14	11,453	5,594	544	5,860	6,138
15	5,860	5,860	278	0	6,138

	TOTAL LOANS	2,544,899
	TOTAL CURRENT	
Year	Interest	Principal
1	122,835	10,009
2	122,408	10,436
3	121,963	10,881
4	121,499	11,345
5	121,015	11,829
6	120,510	12,334
7	119,983	12,860
8	119,434	13,409
9	118,862	13,982
10	118,264	14,579
11	117,641	15,202
12	116,991	15,852
13	116,314	16,530
14	115,607	17,237
15	114,870	17,974
16	114,101	12,605
17	113,590	13,116
18	113,059	13,647
19	112,506	14,199
20	111,931	14,774
21	111,333	0
22	111,333	0
23	111,333	0
24	111,333	0
25	111,333	0

	NEW LOAN				
		163,506		PMT	12,084
	Term	20			
	Rate	4.05%			
Year	Opening	Principal	Interest	Closing	Check
1	163,506	5,462	6,622	158,044	12,084
2	158,044	5,684	6,401	152,360	12,084
3	152,360	5,914	6,171	146,446	12,084
4	146,446	6,153	5,931	140,293	12,084
5	140,293	6,403	5,682	133,890	12,084
6	133,890	6,662	5,423	127,229	12,084
7	127,229	6,932	5,153	120,297	12,084
8	120,297	7,212	4,872	113,085	12,084
9	113,085	7,504	4,580	105,580	12,084
10	105,580	7,808	4,276	97,772	12,084
11	97,772	8,125	3,960	89,647	12,084
12	89,647	8,454	3,631	81,193	12,084
13	81,193	8,796	3,288	72,397	12,084
14	72,397	9,152	2,932	63,245	12,084
15	63,245	9,523	2,561	53,722	12,084
16	53,722	9,909	2,176	43,813	12,084
17	43,813	10,310	1,774	33,504	12,084
18	33,504	10,728	1,357	22,776	12,084
19	22,776	11,162	922	11,614	12,084
20	11,614	11,614	470	0	12,084

	TOTAL NEW	
Year	Interest	Principal
1	129,457	15,471
2	128,809	16,119
3	128,134	16,794
4	127,430	17,498
5	126,697	18,231
6	125,932	18,996
7	125,136	19,792
8	124,306	20,622
9	123,441	21,487
10	122,540	22,388
11	121,601	23,327
12	120,622	24,306
13	119,602	25,326
14	118,539	26,389
15	117,431	27,497
16	116,276	22,514
17	115,365	23,425
18	114,416	24,374
19	113,429	25,361
20	112,402	26,389
21	111,333	0
22	111,333	0
23	111,333	0
24	111,333	0
25	111,333	0

Table 57: Depreciation schedule, existing and with BioClean.

Existing			
Item		Buildings	
Opening		680,000	
DV rate		2.0%	
Years	Opening	Dep	Closing
1	680,000	13,600	666,400
2	666,400	13,328	653,072
3	653,072	13,061	640,011
4	640,011	12,800	627,210
5	627,210	12,544	614,666
6	614,666	12,293	602,373
7	602,373	12,047	590,325
8	590,325	11,807	578,519
9	578,519	11,570	566,948
10	566,948	11,339	555,610
11	555,610	11,112	544,497
12	544,497	10,890	533,607
13	533,607	10,672	522,935
14	522,935	10,459	512,477
15	512,477	10,250	502,227
16	502,227	10,045	492,182
17	492,182	9,844	482,339
18	482,339	9,647	472,692
19	472,692	9,454	463,238
20	463,238	9,265	453,973

Existing			
Item		Plant and Equipment	
Opening		180,000	
DV rate		15.6%	
Years	Opening	Dep	Closing
1	180,000	28,080	151,920
2	151,920	23,700	128,220
3	128,220	20,002	108,218
4	108,218	16,882	91,336
5	91,336	14,248	77,088
6	77,088	12,026	65,062
7	65,062	10,150	54,912
8	54,912	8,566	46,346
9	46,346	7,230	39,116
10	39,116	6,102	33,014
11	33,014	5,150	27,864
12	27,864	4,347	23,517
13	23,517	3,669	19,848
14	19,848	3,096	16,752
15	16,752	2,613	14,139
16	14,139	2,206	11,933
17	11,933	1,862	10,071
18	10,071	1,571	8,500
19	8,500	1,326	7,174
20	7,174	1,119	6,055

Existing			
Item		Vehicles	
Opening		104,000	
DV rate		15%	
Years	Opening	Dep	Closing
1	104,000	15,600	88,400
2	88,400	13,260	75,140
3	75,140	11,271	63,869
4	63,869	9,580	54,289
5	54,289	8,143	46,145
6	46,145	6,922	39,224
7	39,224	5,884	33,340
8	33,340	5,001	28,339
9	28,339	4,251	24,088
10	24,088	3,613	20,475
11	20,475	3,071	17,404
12	17,404	2,611	14,793
13	14,793	2,219	12,574
14	12,574	1,886	10,688
15	10,688	1,603	9,085
16	9,085	1,363	7,722
17	7,722	1,158	6,564
18	6,564	985	5,579
19	5,579	837	4,742
20	4,742	711	4,031

Existing	
Total Depreciation	
Years	
1	57,280
2	50,288
3	44,335
4	39,263
5	34,936
6	31,241
7	28,081
8	25,374
9	23,051
10	21,054
11	19,334
12	17,847
13	16,560
14	15,441
15	14,466
16	13,613
17	12,864
18	12,202
19	11,617
20	11,095

New			
Item		Effluent system	
Opening		103,506	
DV rate		15%	
Years	Opening	Dep	Closing
1	103,506	15,526	87,980
2	87,980	13,197	74,783
3	74,783	11,217	63,566
4	63,566	9,535	54,031
5	54,031	8,105	45,926
6	45,926	6,889	39,037
7	39,037	5,856	33,182
8	33,182	4,977	28,204
9	28,204	4,231	23,974
10	23,974	3,596	20,378
11	20,378	3,057	17,321
12	17,321	2,598	14,723
13	14,723	2,208	12,514
14	12,514	1,877	10,637
15	10,637	1,596	9,042
16	9,042	1,356	7,685
17	7,685	1,153	6,533
18	6,533	980	5,553
19	5,553	833	4,720
20	4,720	708	4,012

New	
Total Depreciation	
Years	
1	72,806
2	63,485
3	55,552
4	48,797
5	43,041
6	38,130
7	33,936
8	30,351
9	27,282
10	24,650
11	22,390
12	20,445
13	18,768
14	17,318
15	16,062
16	14,969
17	14,016
18	13,182
19	12,450
20	11,803