DEALING WITH SIN: A NOVEL SOLUTION

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ABSTRACT

The discharge of soluble inorganic nitrogen (SIN) to the Ōroua River from the Feilding Wastewater Treatment Plant (WWTP) has caused the Manawatū District Council (MDC) many headaches over the years. However, shifting from river discharge to land application of treated effluent triggered the law of unintended consequences; for the WWTP, which does not remove enough SIN for discharge to river, removes too much for land irrigation. This left MDC in the unenviable position of having to fertilise the crops irrigated with treated effluent.

A significant portion of the organic and nitrogen load to the WWTP is from trade waste contributors. Unlike a traditional nutrient removal WWTP, the Feilding WWTP has an anaerobic lagoon at the front end, which transforms a portion of this nitrogen into inorganic ammonia. Subsequent ponds with cycling aeration nitrify this ammonia but have proved unsuccessful in also denitrifying, further exacerbating the SIN problem.

The existing anaerobic digester reaching the end of its design life provided a timely opportunity for reconsidering overall operation of the WWTP. By diverting the high-strength trade wastes from the WWTP to the anaerobic digester for codigestion with the secondary sludge, thus creating a Waste-to-Energy facility, which will achieve the following four outcomes:

- Substantially reduce the effluent SIN, suitable for river discharge when the land area is saturated.
- Substantially increase the energy yield from the anaerobic digester(s).
- Substantially reduce the operating costs of the WWTP.
- Produce a nutrient-rich digestate to fertilise the crops irrigated with treated effluent.

This paper will present the challenges and the opportunities for an inland rural community with substantial trade waste contributors. It will discuss the risks and benefits of dealing with SIN by codigesting trade wastes with WAS to boost energy yield.

KEYWORDS

Trade waste, anaerobic digestion, waste-to-energy, codigestion, nutrients

PRESENTER PROFILE

Jared Mayes has ten years' experience as a wastewater Process Engineer, working for municipal and industrial clients in conventional and exotic locations. He has particular experience the waste-to-energy sector and anaerobic digestion in particular to capture the latent energy within waste and use it for heat and power generation.

Chris Pepper is a CPEng with over 30 years' municipal infrastructure experience, maintaining focus on minimising the cost, the carbon emissions, and the environmental impacts of municipal infrastructure. He is keen on demonstrating how the opportunities to manage this infrastructure sustainably can be incorporated into the long term and project planning processes.

1 INTRODUCTION

1.1 Background

The Manawatū District Council (MDC) operates the Feilding wastewater treatment plant (WWTP) which treats the domestic and industrial wastewaters generated by the Feilding township and the nearby community of Bunnythorpe, serving over 14,000 residents. The local industries are mostly related to the transport, sale, and processing of livestock, contributing only 25% of the flow but over 60% of the load.

The Feilding township has been reticulated since 1905 with wastewaters treated in a large septic tank until the current WWTP was built in 1967. The WWTP has been upgraded over the years in response to increasing domestic/industrial demand and more stringent environmental standards.

Currently the WWTP has two discharge consents, the first (and preferred) is a 35 year consent for irrigation to 115 ha of nearby land that it is managed with a cut and carry system, the second is a 10 year consent for discharge to the Ōroua River (which is used when the soil is too saturated to accept additional volume). These two discharge consents impose very different conditions upon the treated wastewater quality, the first requiring an annual nutrient balance and pathogen removal, the second with more stringent limits especially upon soluble inorganic nitrogen (SIN) and pathogens, and very tight limits upon dissolved reactive phosphorus (DRP).

This has resulted in two different operating regimes required for the WWTP depending upon the discharge environment, when irrigating to land it is desirable to maximise the amount of nutrients in the wastewater in order to optimise the grass growth, whereas when discharging to river it is required to minimise the amount of nutrients. Unfortunately the WWTP achieves neither of these two objectives, inasmuch as it regularly exceeds the consented SIN limits for discharging to the river, but requires supplementary fertiliser when irrigating to land.

Recently the existing concrete digester at the WWTP, which was built in 1967, reached the end of its design life and MDC decided to replace the digester with a new steel digester, and decommission and rehabilitate, if possible, the existing digester. As part of the replacement of the existing digester MDC decided to optimise its utilisation in the context of the overall plant operation and performance.

1.2 Overview of Feilding WWTP

The Feilding WWTP presently consists of preliminary treatment of screening and grit removal, followed by organic load shaving and flow buffering in an anaerobic lagoon with a design 3.5 day hydraulic residence time. Primary sludge settles out in the lagoon and is partially digested to reduce the volume. The sludge that accumulates in the 'anaerobic' lagoon is periodically removed manually to landfill.

Aerated lagoons provide secondary treatment of the anaerobic lagoon effluent with attached growth curtains and cycling aeration to provide nitrification and denitrification. Secondary sludge then settles out in sedimentation tanks. Biological trickling filters remove dissolved pollutants in the secondary treated effluent, which then returns to the sedimentation tanks to settle out the biomass. Alum is dosed to remove phosphorus for discharge to river. The effluent is then polished using Actiflo sand filtration followed by cloth disk filters, with tertiary sludge returned to the anaerobic lagoon where it collects with the primary sludge. Figure 1 summarises the overall layout of the WWTP.

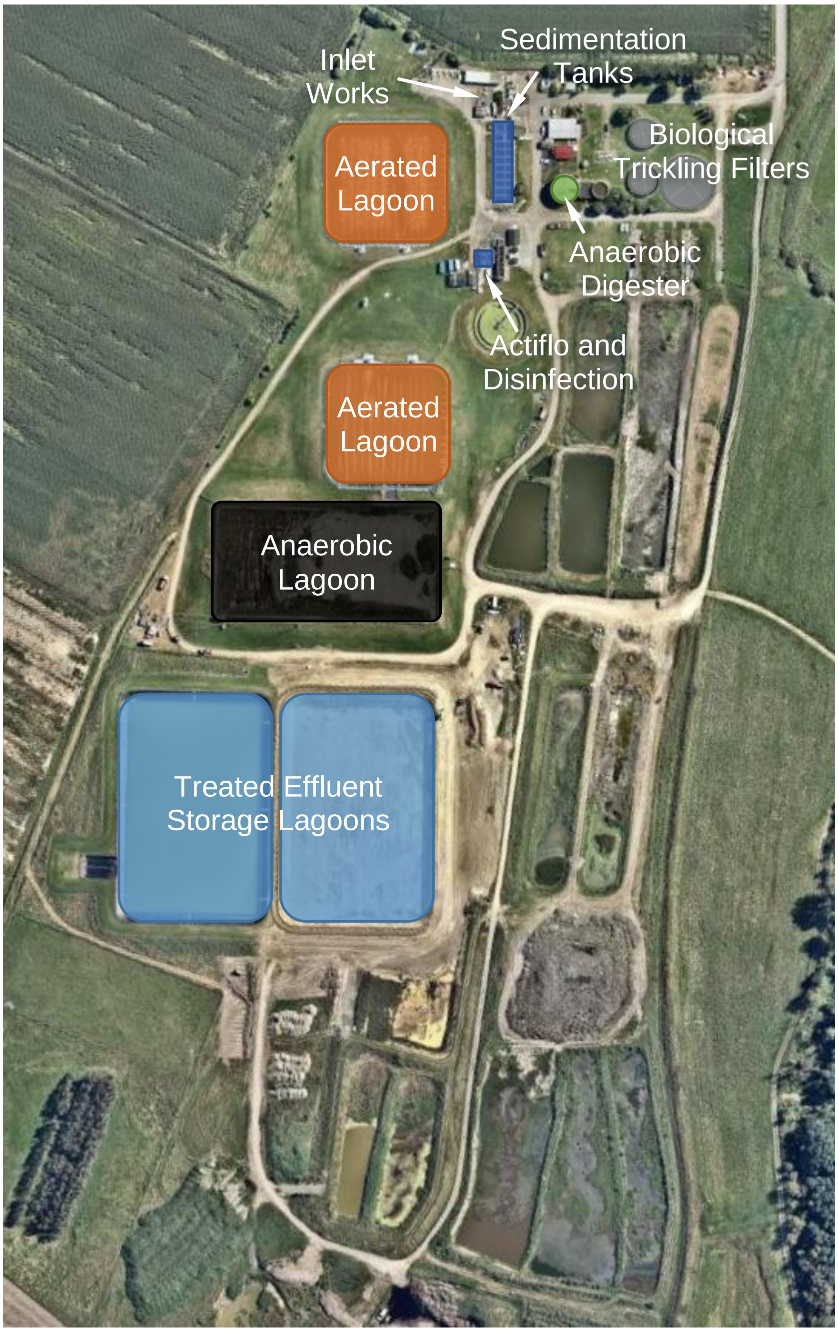

Figure 1: Feilding WWTP Site Layout

The treated wastewater is then UV disinfected and either to treated effluent storage lagoons for irrigation to land or discharged to the Ōroua river when the soil is saturated and unable to accept additional water. The land irrigated with the treated wastewater also requires the application of fertilisers in order to optimise the crop growth. Figure 2 summaries the process flow of the WWTP.

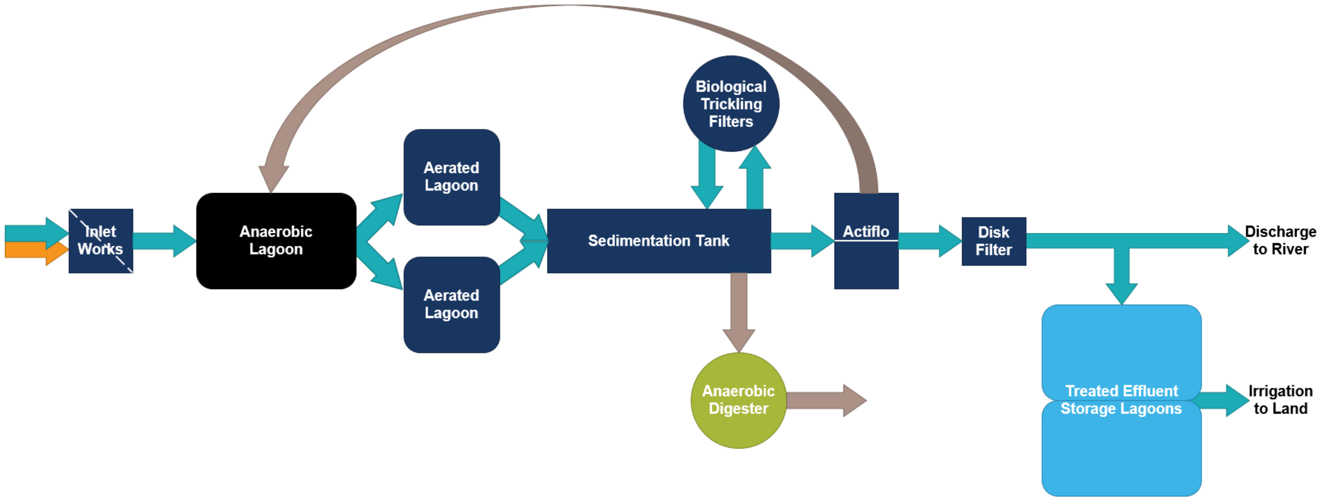

Figure 2: Feilding WWTP Current Process Flow Diagram

The secondary sludge from the sedimentation tank is anaerobically digested to reduce the volume in a 1,650m^3 concrete digester (that was built in 1967). Anaerobic digestion is the biological degradation process undertaken in the absence of oxygen generating methane-rich biogas, and reducing and stabilising the organic matter for disposal or reuse as a fertiliser. Anaerobic digestion is performed by a series of microorganisms working in concert, as shown in the figure below, and has two optimal temperature ranges 35 –40°C (mesophilic) and 55 - 57°C (thermophilic), and has an optimal pH range of 6 – 9.

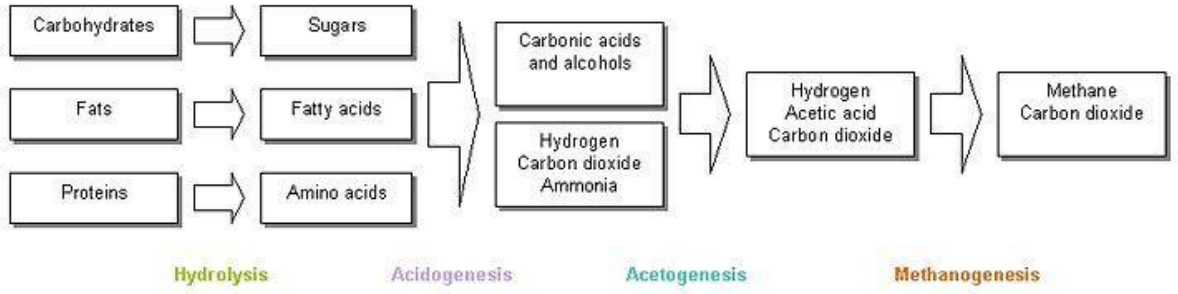

Figure 3: The Anaerobic Digestion Process

The digested sludge is disposed of to sludge ponds. The digester is heated by recirculating digestate from the digester through a hot water boiler. The hot water is heated by either the biogas generated from anaerobic digestion, or natural gas (the two fuels are not blended). The biogas is scrubbed with an iron sulphide scrubber and a gasholder provides buffering and storage. Excess biogas is flared.

1.3 Nitrogen through the WWTP

Nitrogen in wastewater is comprised of organic and inorganic forms of nitrogen, of which roughly one third is organic. The term organic nitrogen, as the name suggests, is associated with nitrogen bound in organic matter and covers a wide range of chemical compounds, from amino acids, amino sugars, and proteins, and roughly 50-75% is bound in particulate organic matter (Randtke, et al., 1978). Inorganic nitrogen specifically relates to the ammonia, ammonium, nitrite, and nitrate. It is worth noting that as these compounds are all soluble, then soluble inorganic nitrogen (SIN) is directly comparable to total inorganic nitrogen (TIN).

Untreated wastewater contains organic nitrogen and ammonia, with nitrate and nitrite typically undetectable. In a conventional wastewater treatment plant, either with primary sedimentation or without, followed by secondary treatment, nitrogen is removed in the following ways:

- Particulate organic nitrogen is incorporated into the sludge and removed from the treatment process, while approximately 60-75% of the soluble organic nitrogen is converted to soluble inorganic nitrogen through the treatment plant (Randtke, et al., 1978).

- SIN is removed by the nitrification – denitrification process. Nitrification is the conversion ammonia to nitrate by bacteria under aerobic conditions. Denitrification is conversion of nitrate to nitrogen gas under anoxic conditions. A well-designed nitrification / denitrification WWTP can achieve Total Nitrogen concentrations of less than 1 mg/L.

However, at the Feilding WWTP the secondary treatment process is proceeded by an anaerobic process. In the anaerobic process the particulate organic nitrogen is converted to ammonia. This results in the ammonia concentration increasing from 20 – 50 mg/L in the untreated wastewater to roughly 80 mg/L in the influent to the aerated lagoons, a significant increase in the SIN requiring removal. The aerated lagoons do well therefore to reduce the ammonia to around 20 mg/L and the SIN to around 30 – 35 mg/L. However, this is still results in river discharges being non-compliant in terms of SIN, but is insufficient SIN for the volume of wastewater irrigated resulting in MDC needing to apply fertilise the irrigated land.

Furthermore, the anaerobic lagoon is a necessary part of the process as it provides load shaving, reducing the organic load by between 30 – 60%. Therefore, alternative approaches to reducing the SIN were required.

2 THE INDUSTRIES

2.1 Industrial Load Contribution

There are eight significant industries, which currently discharge to the Feilding WWTP:

- Two meat works
- Three stock truck washes
- A skinning operation
- A saleyards
- A processor extracting high-end product from blood

Figure 4 shows that proportion contribution of each of these contributors. As can be seen the industries contribute only a fraction of the flow but the majority of the COD, solids, and organic nitrogen load.

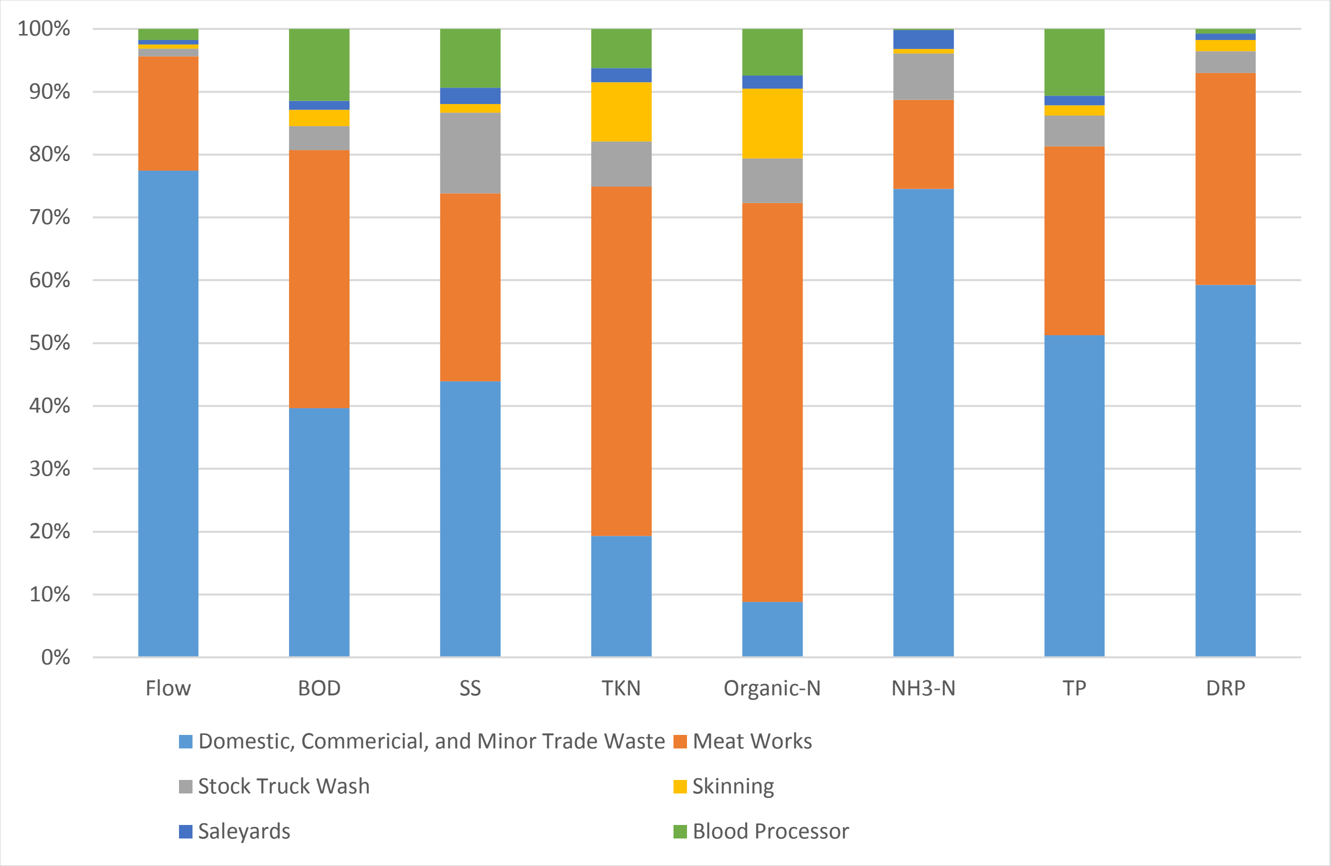

Figure 4: Proportion Load Contribution by Source

If the waste from these contributors was separated at source, then this would divert these high loads away from the WWTP, achieving the following benefits:

- Reduced primary sludge accumulation within the anaerobic lagoon.
- Reduced ammonia production within the anaerobic lagoon, and hence the amount of SIN requiring removal in the aerated lagoons.
- Reduced organic load through the WWTP.

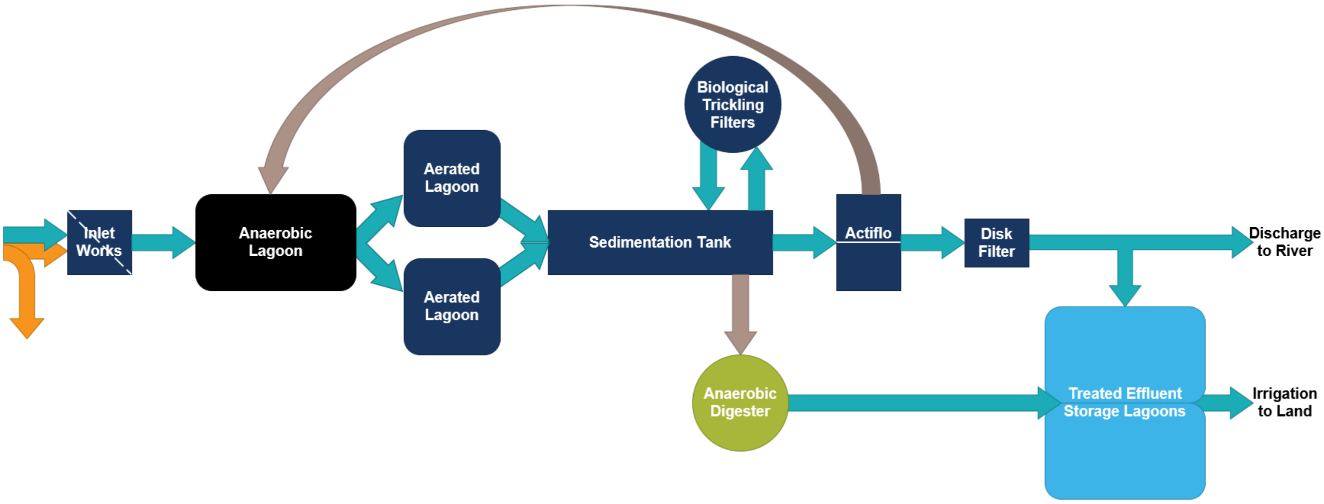

Figure 5: Feilding WWTP with Source Separation

2.2 Source Separation

The trade waste from the meat works and the blood processor were identified as the two industries to target initially for source separation, as they contribute a significant portion of the organic nitrogen load upon the WWTP and are easiest to source separate.

2.2.1 MEAT WORKS WASTEWATER

The source separation of the meat works waste will utilise a currently unused pipeline that runs parallel to the existing combined sewer network past the meat works (and indeed the majority of the industries), as shown in Figure 6. Therefore, this pipeline will be used as a trade waste sewer collecting the wastewater from the meat works thus allowing it to be treated separately from the low strength municipal wastes.

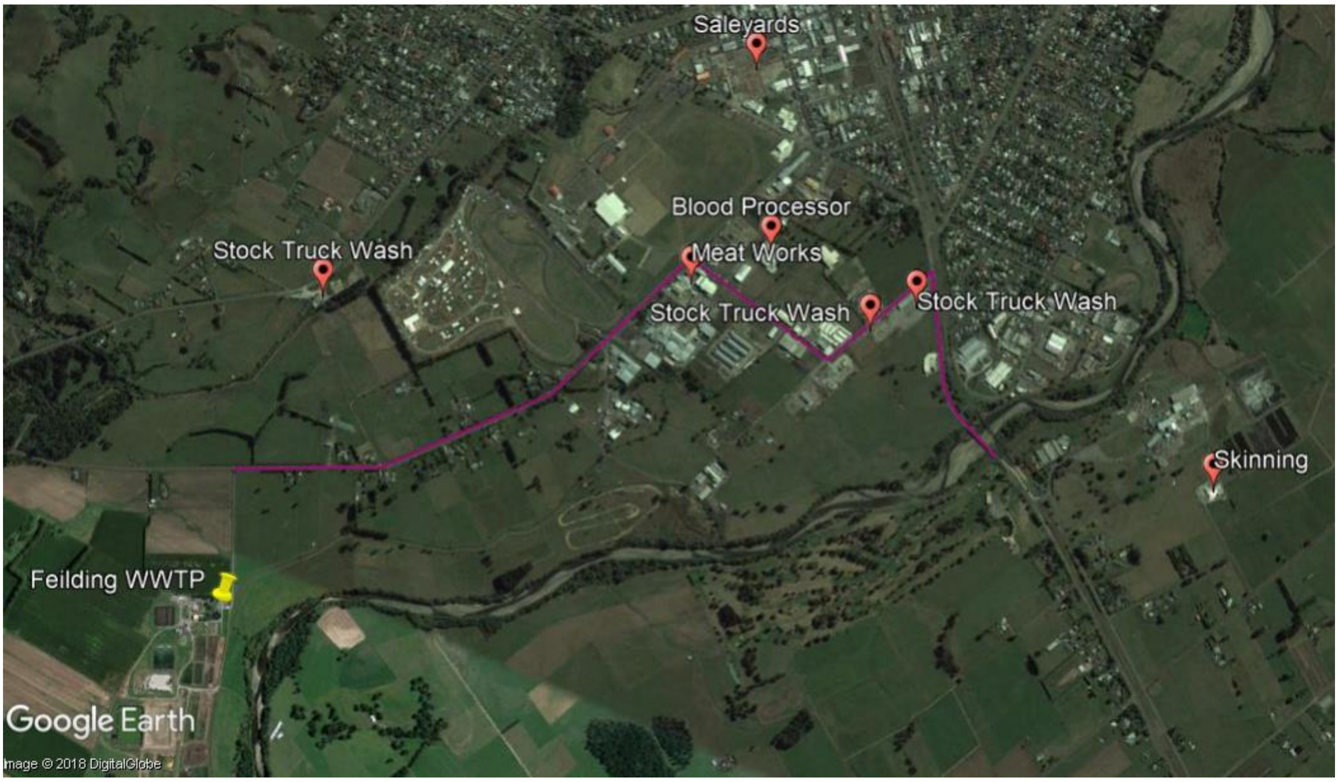

Figure 6: Trade Waste Sewer

2.2.2 BLOOD PROCESSOR WASTE

Furthermore, the trade waste from the blood processor currently is comprised of a blend of high-strength sludge, at ~ 8% solids, with low strength wastewater. Figure 7 shows the proportional contribution of the two waste streams from the blood processor. By collecting The high-strength sludge can be separated before blending with the low strength wastewater and trucked to the WWTP, this will reduce the organic and nutrient load upon the WWTP.

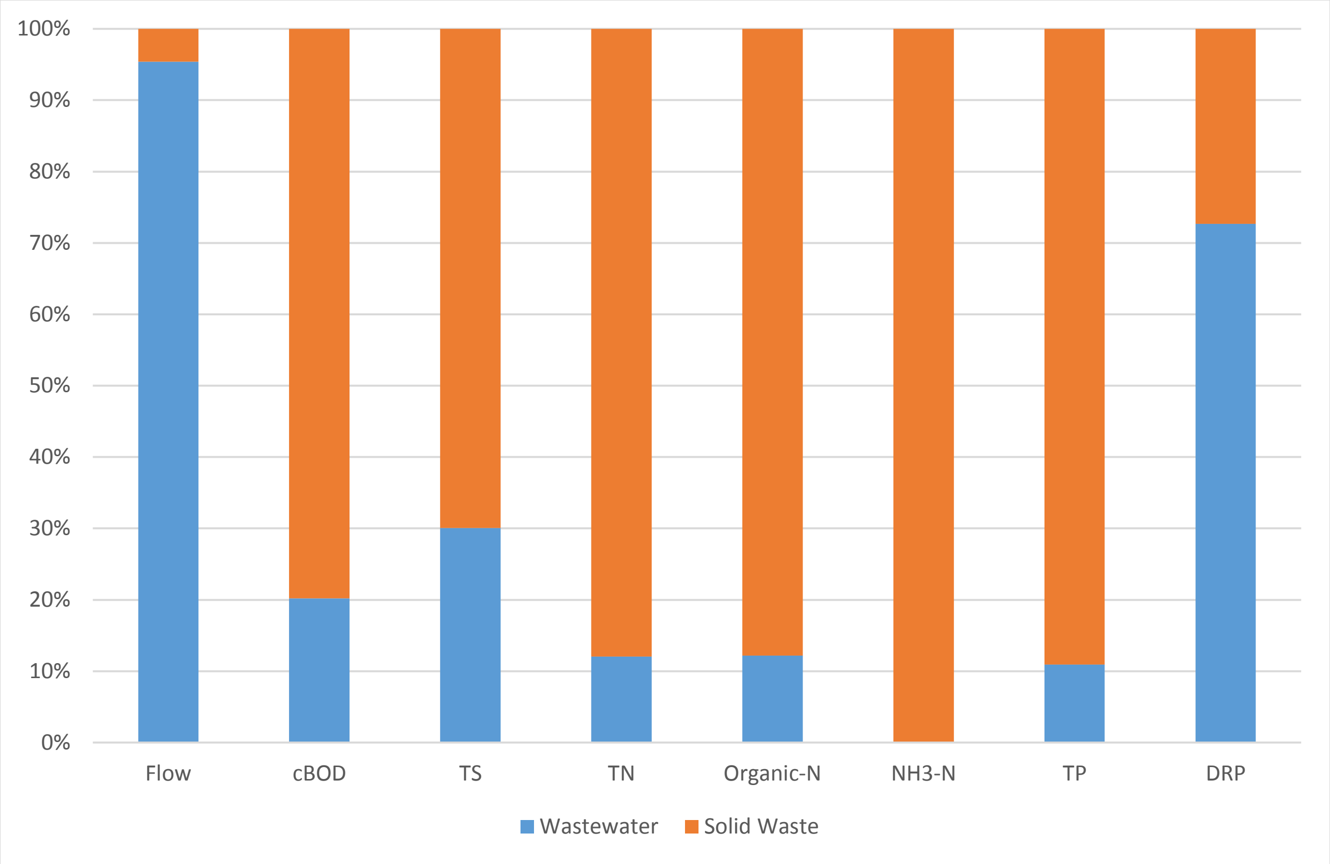

Figure 7: Blood Processor Waste Stream Proportional Contribution

2.3 Treatment of Source Separated Wastes

The source separated wastes were identified as suitable feedstocks for codigestion, due to their high organic load. Codigestion is the combined digestion of multiple biodegradable feedstocks in an anaerobic digestion system. The advantage of codigestion is the ability to maximise the generation of biogas an anaerobic digestion system, in some cases utilising complimentary feedstocks results in a greater biogas yields than digesting the feedstocks separately (i.e. digesting a nutrient-rich feedstock, which may otherwise experience nutrient toxicity, together with a nutrient-poor feedstock results in a greater net biogas yield). Furthermore, the effects of the seasonal fluctuations in load can be minimised by judicious selection of codigestion feedstocks, i.e. by selecting feedstocks whose seasons are complimentary the digester/s can be operated at design capacity throughout the year thus maximising the annual gas yield maximised.

A codigestion reception facility will be installed at the WWTP, which will receive the source separated wastes and process them suitable for anaerobic digestion. The wastes will be pumped to the digestion facility for anaerobic digestion. The digestate, digested wastes, will then be dewatered and the nutrient rich centrate used to replace the inorganic fertilisers required for land irrigation. Finally, the biogas produced will be processed and used to generate heat for the digesters and electricity for use on site. This overall system is termed the Waste-to-Energy (WtE) Facility.

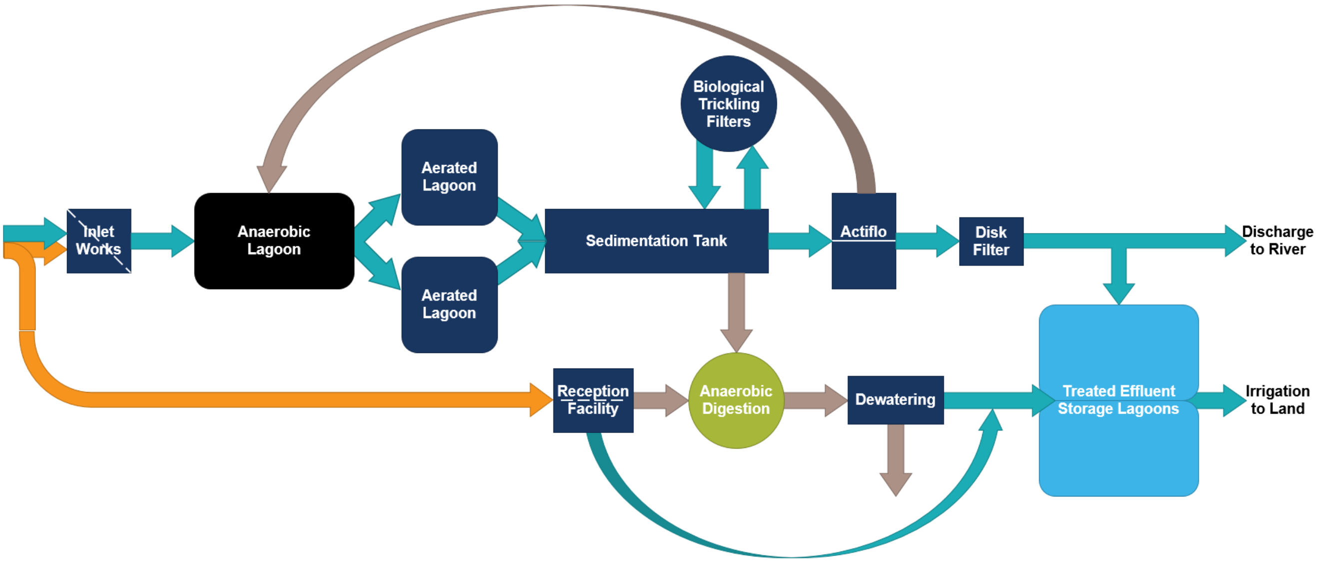

Figure 8: Waste-to-Energy Facility

3 WASTE-TO-ENERGY FACILITY

3.1 Codigestion Reception Facility

In order to be suitable for anaerobic digestion the source separated wastes require processing in order to ensure that they will not cause issues during digestion. The processing requirements for each stream are discussed below.

3.1.1 MEAT WORKS WASTEWATER

The meat works wastewater as delivered to the factory has very low solids relatively speaking. If it was added directly to the digester the solids retention time (SRT) would be less than 1 day, which is too short for conventional anaerobic digestion. The shorter the SRT the less volatile solids destruction will occur, which in turn decreases the biogas and energy yield from the anaerobic digester.

In order to improve the SRT, the wastewater(s) require thickening either:

- Before the anaerobic digester (pre-thickening), or
- After the anaerobic digester, returning the anaerobic sludge to the digester thus decoupling the SRT from the HRT (recuperative thickening).

Pre-thickening was selected in this instance as the base SRT was deemed too short for recuperative thickening, and would present a significant avoidable operational risk, inasmuch that if the recuperative thickening malfunctioned there is a high likelihood of losing a significant portion of the anaerobic sludge (digester 'wash-out). The solids captured from the pre-thickening will be sent to the anaerobic digesters, while the filtrate will be treated for solids and pathogens and blended with the treated wastewater for irrigation.

3.1.2 BLOOD PROCESSOR WASTE

The high-strength waste from the blood processor will be transported to site by vacuum tanker. The trucks will unload to a storage tank connecting to a flexible hose with a camlock coupling. A rock trap to remove any inorganics such as rocks and metal and a grinder/macerator to reduce the size large organics, will prevent the downstream pumps and piping from clogging. Pumps will dose the contents of the tank into the digester at a controlled rate.

3.2 Digestion

The existing concrete digester has reached the end of its design life and a new steel digester is currently being installed, so that the existing digester can be decommissioned or rehabilitated if possible. This will be operated as a conventional mesophilic digester until its capacity is exceeded. Mesophilic digestion is the most common form of anaerobic digestion, and is robust, stable, and provides a consistent digested sludge (digestate) quality.

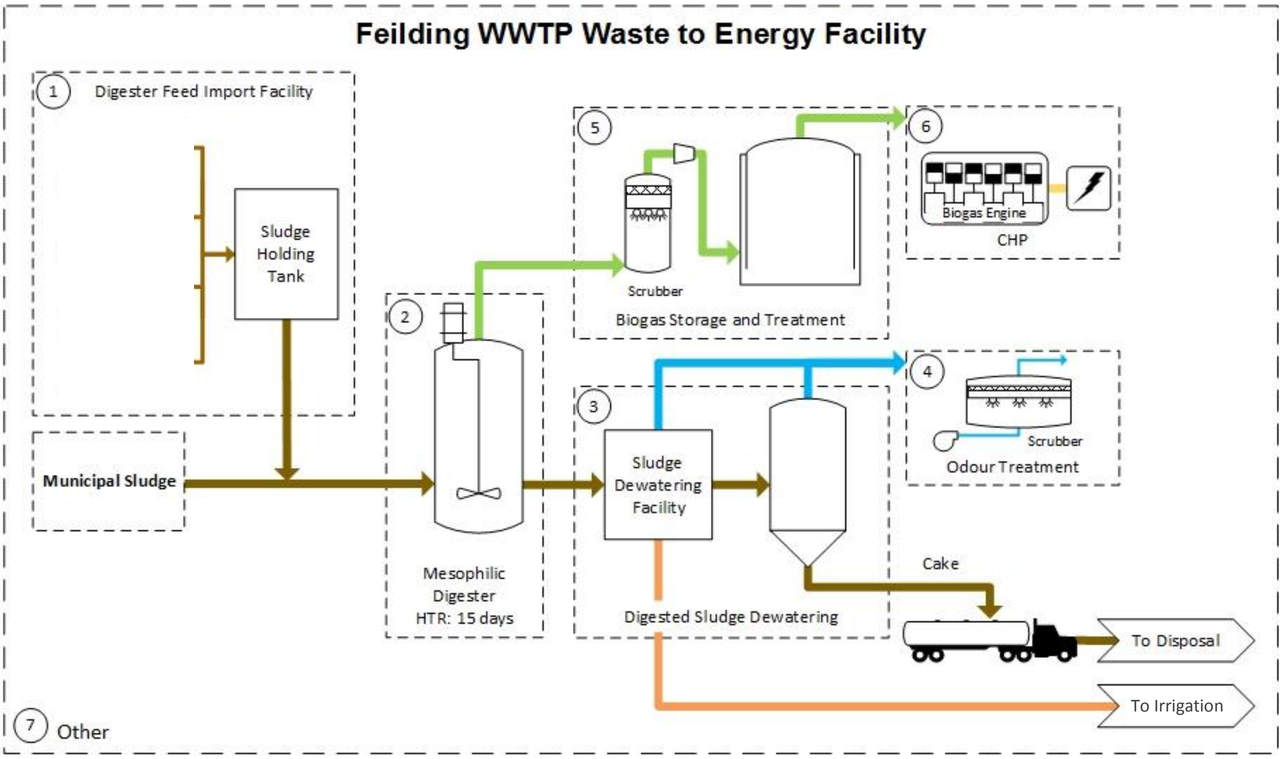

Figure 9: Mesophilic Digestion Process

Once the capacity of the digester is exceeded then an additional anaerobic digester will be installed and the digesters will operate in a temperature phased configuration. Temperature (or Thermally) Phased Anaerobic Digester (TPAD) is a two stage anaerobic digestion process in which the first tank operates at thermophilic conditions (55°C) and the second tank operates at mesophilic conditions (37°C). The TPAD process achieves Grade A biosolids by having sufficient residence time within the thermophilic digester. TPAD process combines the improved biogas yield and volatile solids destruction from thermophilic digestion, with the mesophilic digestion removing the VFAs from the thermophilic effluent, thus reducing the odour. TPAD has been successfully applied to the digestion of municipal sludge, paunch, blood and paunch, and abattoir DAF sludge.

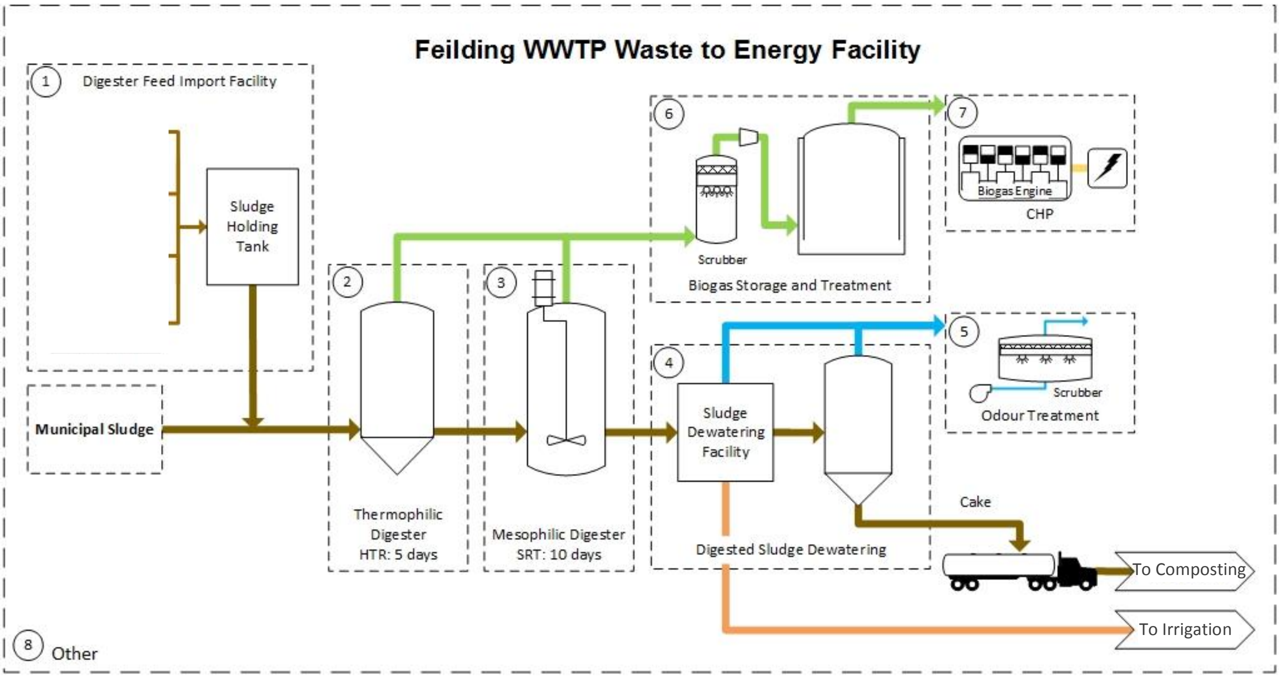

Figure 10: Temperature Phased Anaerobic Digestion Process

3.3 Biogas Utilisation

Biogas from anaerobic digestion is primarily composed of methane (CH_4) and carbon dioxide (CO_2), with trace amounts of hydrogen sulphide (H_2S) and ammonia (NH_3). It is typically saturated with water vapour, and at the same temperature as the digester. Biogas from municipal sources will also contain siloxanes. Reciprocating internal engines will convert this biogas into electricity and heat. The biogas will be scrubbed to remove H_2S, dried, and pressurised before being sent to the engines for combustion. A portion of the heat generated will be used to heat the digesters and the electricity used to supply the onsite electricity requirements.

4 THE RISKS

4.1 Inhibition

4.1.1 AMMONIA

The highest risk to the upgrade is ammonia inhibition, as although the source separated trade wastes have high organic load they also have high organic nitrogen content. Nitrogen is the nutrient most required for the growth of microorganisms. Under anaerobic conditions, nitrogen in the forms of nitrite and nitrate is not available for bacterial growth, as they are reduced to nitrogen gas and released with the biogas.

The main sources of nitrogen used by anaerobic bacteria are ammonia and the fraction of organic nitrogen converted to ammonia by degradation of particulate matter. Ammonia is a strong base, which neutralizes the volatile acids produced by fermentative bacteria, and thus helps maintain neutral pH conditions essential for cell growth. However, an overabundance of nitrogen in the substrate can lead to excessive ammonia formation, resulting in toxic effects. Dissolved ammonia in the liquid is toxic to anaerobic bacteria above 80 mg/L NH_3-N, and the ammonium ion is moderately inhibitory at concentrations greater than 1,500 mg/L and strongly inhibitory above 3,000 mg/L (Metcalf & Eddy, 2014). Thus, it is important that the proper amount of nitrogen be in the feedstock, to avoid either nutrient limitation (too little nitrogen) or ammonia toxicity (too much nitrogen).

It is estimated that the ammonium concentration could reach up to 1,000 mg/L in the digester, which is high but not toxic. Ammonium concentration, alkalinity and pH in the digester will be monitored intensively in order to ensure that the concentrations do not become problematic and that the ammonium does not become ammonia.

4.1.2 SALTS

The high-strength sludge from the blood processor contains potentially high concentrations of sodium. Cationic salts, such as Sodium, Potassium, Calcium, and Magnesium, up to certain concentrations are beneficial to anaerobic digestion, however, above certain threshold the salt ceases to be beneficial and begins to inhibit the anaerobic activity finally causing the biological activity to cease. It is expected that dilution will reduce the concentration of sodium to 'safe' thresholds throughout most of the year. However, regular monitoring will be carried out to identify if inhibition is occurring.

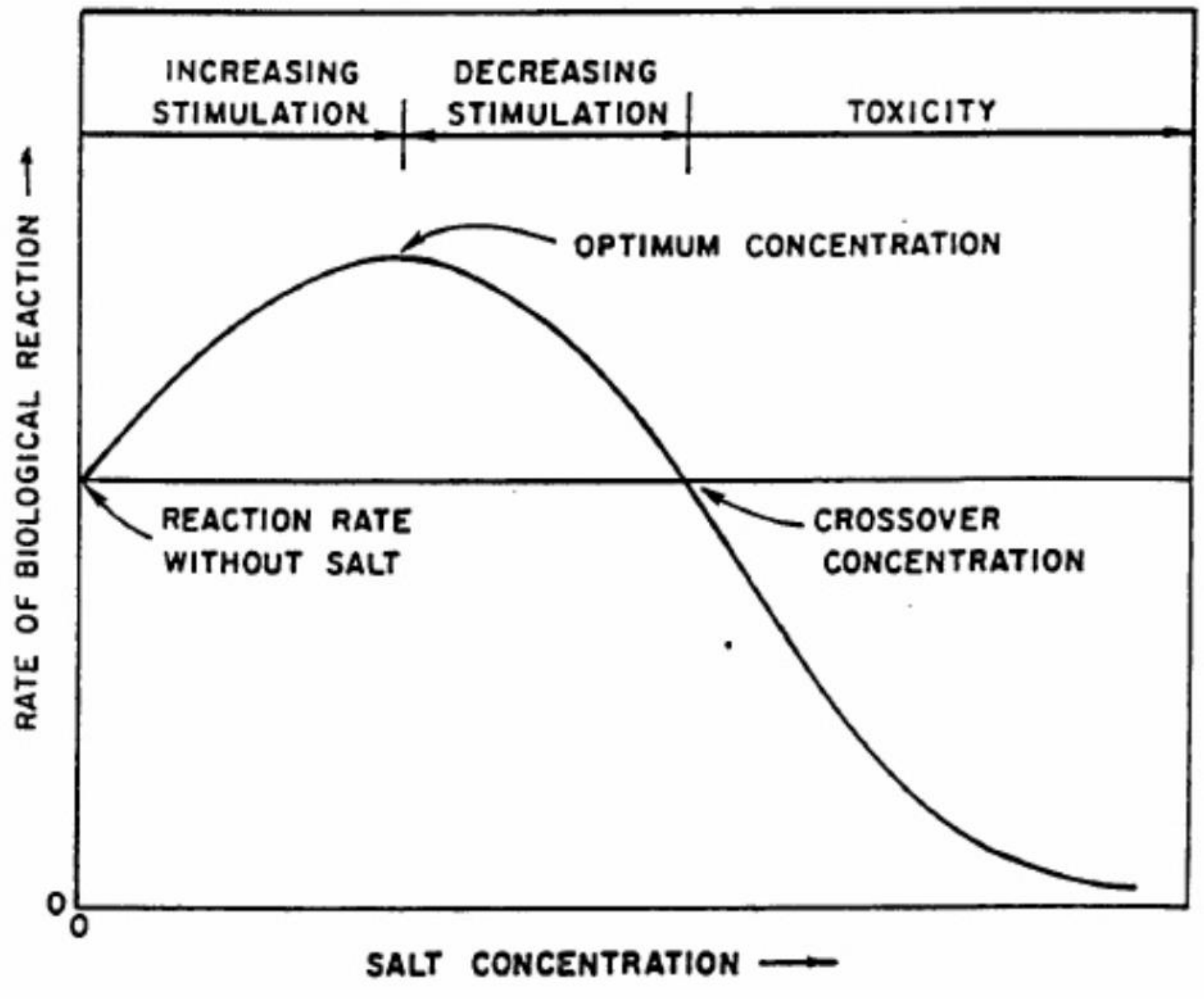

Figure 11: General effect of salts on biological reactions (McCarty, 1964)

4.2 Seasonality

All of the trade waste contributors, aside from the blood processor, are affected by seasonality, including the WWTP. The low yield point for the industries coincides for the low yield point for the WWTP during July and August, as can be seen in Figure 12 below, this means that the digester will be subject to very low loadings during winter.

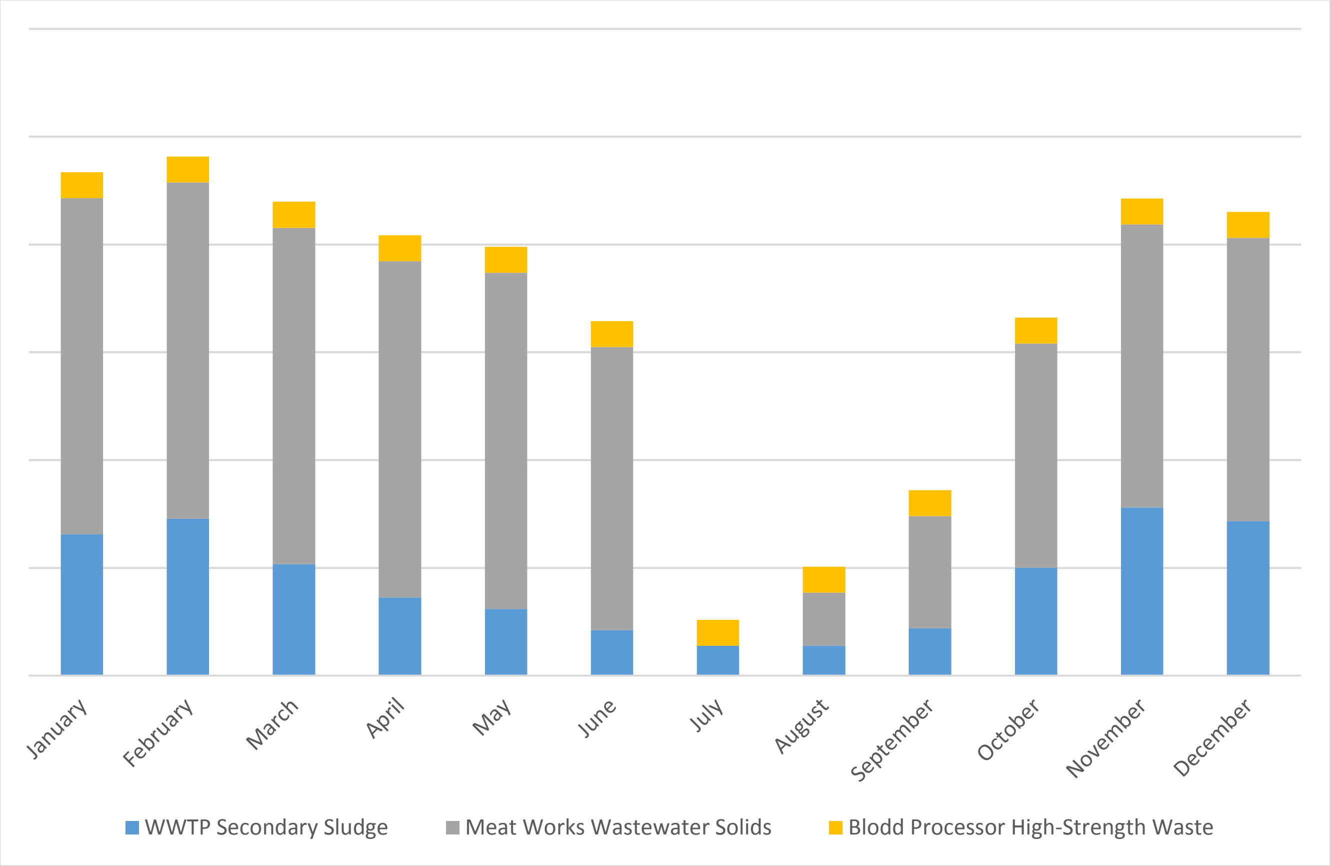

Figure 12: Estimated Seasonal Loads from Codigestion Feedstocks

Since the load is substantially decreased in winter there is a risk that the system will be more prone to upsets during winter due to the higher heat requirements and reduced biogas yield, which means any loss in biogas production may result in insufficient biogas heat to heat the digester. Natural gas would therefore be required to supply the necessary heat.

5 THE REWARDS

5.1 Improved WWTP Performance

Diverting the meat works and the blood processor trade wastes from the WWTP to the WtE facility, will decrease the organic nitrogen load to the WWTP by over 70%. This will substantially decrease the amount of organic nitrogen available for conversion to ammonia and thus requiring removal within the aerated lagoons. Therefore, the WWTP will be able to achieve the consented SIN limits. Furthermore, the diversion of the trade waste contributors will also decrease the organic load and hence the aeration demand in the aerated lagoons.

5.2 Energy

The anaerobic co-digestion of the high-strength trade wastes will result in a significant amount of energy-rich biogas. This biogas will be processed and used in engines to generate heat and electricity. The heat generated from the biogas will be sufficient to heat the digesters, greatly reducing the amount of natural gas that is sometimes required at present to heat the digester. The electricity generated will be used to reduce the operating cost of the WWTP.

5.3 Nutrient-Rich Digestate

Due to the high organic nitrogen content of the trade wastes fed into the WtE facility, the digestate will be rich in ammonium. Ammonium is a form of nitrogen that is readily available for crops and grasses, which makes it ideal for fertiliser. The digestate will be used to replace most if not all of the fertiliser currently being applied by MDC to the land irrigated by wastewater, thus further reducing operating costs.

5.4 Additional Waste Streams

As discussed above, it is anticipated that there will be a period of the year between July and September where the waste-to-energy facility is lowly loaded. However, the digesters and biogas train need to be sized for the peak summer flow rate. This means that there will be capacity to accept more feedstocks and hence generate more electricity during winter by utilising additional feedstocks. This also offers additional benefits to the wider community taking wastes that normally are costly to dispose to landfill. The additional feedstocks that have been considered are:

- Paunch from the meat works
- DAF Sludge from nearby milk factory
- Silage from the land application of treated wastewater
- Primary sludge from Feilding WWTP
- Connecting other existing trade waste contributors to the trade waste sewer.
- Connecting additional industries currently not connected to the combined sewer to the trade waste sewer.

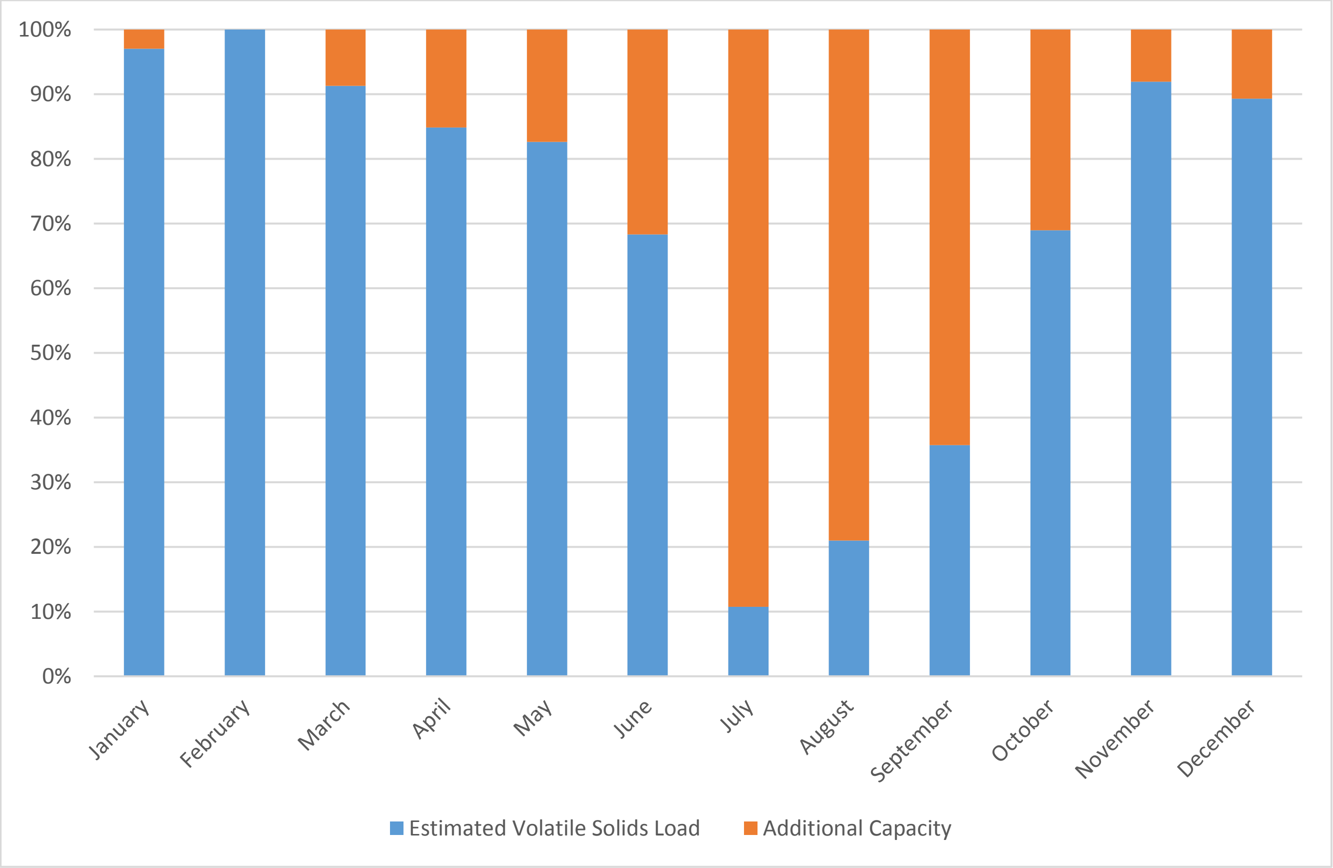

Figure 13: Estimated Additional Seasonal Capacity Available

6 CONCLUSIONS

A significant portion of the organic nitrogen load to the Feilding WWTP is from trade waste contributors. Unlike a traditional nutrient removal WWTP, the Feilding WWTP has an anaerobic lagoon at the front end, which transforms a large portion of this organic nitrogen into inorganic ammonia. Subsequent ponds with cycling aeration nitrify this ammonia but have proved unsuccessful in also completely denitrifying. This results in the treated effluent exceeding the soluble inorganic nitrogen (SIN) limits for discharge to the Ōroua River. However, in order to irrigate the treated wastewater to land, fertiliser is required to supply the nitrogen requirements of the crops, at a significant cost. Diverting these trade wastes from the WWTP would avoid these issues.

The existing anaerobic digester is reaching the end of its design life and required refurbishment and/or replacement. A waste-to-energy system, consisting of a codigestion reception facility, temperature phased anaerobic digestion, biogas treatment, and combined heat and power engines, will be implemented to maximise the energy yield from the anaerobic digester high-strength trade wastes can be diverted from the WWTP to the anaerobic digester.

This option is not without risk as ammonium/ammonia at high concentrations is inhibitory and if high enough toxic to anaerobic bacteria. The anaerobic digestion of feedstocks that contain large amounts of organic nitrogen will produce significant amounts ammonium/ammonia. Careful monitoring and control will be implemented to reduce the risk of inhibition and toxicity.

However, by taking advantage of the end-of-life existing anaerobic digester and implementing a Waste-to-Energy facility, the MDC will be able to divert high-strength trade wastes from the WWTP. This will benefit the overall WWTP operation in the following ways:

- Substantially reduce the effluent SIN, suitable for river discharge when the land area is saturated.
- Produce electricity for use at the WWTP.
- Produce a nutrient-rich digestate to fertilise the crops irrigated with treated effluent.
- Allow for the reception of additional waste streams for digestion.

7 REFERENCES

McCarty, P. L., 1964. Anaerobic Waste Treatment Fundamentals. *Public Works Journal,* Volume 95.

Metcalf & Eddy, 2014. *Wastewater Engineering: Treatment, Disposal, and Reuse.* 5 ed.:McGraw-Hill.

Randtke, S. J. et al., 1978. *Soluble Organic Nitrogen Characteristics and Removal,* Ohio: US EPA.