REGIONAL BIOSOLIDS STRATEGY
LOWER NORTH ISLAND

Report 9: Biosolids Processing Trials; Biosolids Composting Trial Final Report

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Regional Biosolids Strategy – Lower North Island

Report 9: Biosolids Processing Trials; Biosolids Composting Trial Final Report

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1 EXECUTIVE SUMMARY

Background

The MfE Waste Minimisation funded project "Collective Biosolids Strategy – Lower North Island" is taking a collaborative approach to sludge management with the aim to develop a regional biosolids strategy focussing on beneficial end-use. The project has tested the feasibility of a selection of potential end-use options through on ground application (research trials) and desktop feasibility/cost analysis. One of these trials has investigated the practical and/or technical viability of sludge composting by way of a large-scale field trial.

Aims

The purpose of this report is to outline the methods, processes and results of a large-scale sludge composting trial designed to determine if a high-quality compost product could be produced from varying mixtures of contrasting sludge.

Trial

This report outlines the set up and results of this trial summarised as follows:

- A large-scale field trial was established at the PNCC Awapuni composting facility throughout early 2019;
- The trial consisted of 12 windrows of sludges mixed with green waste at a ratio of 1:4 (237 m^3 of material forming 12 m long windrows);
- Three contrasting sludge types were chosen and blended either individually or in combination:
    - Palmerston North WWTP digester sludge;
    - Palmerston North WWTP alum sludge; and
    - Bunnythorpe oxidation pond sludge
- The compost windrows were tested at establishment and monthly for an array of parameters to assess the microbial and chemical contaminants present and the effectivity of the composting process; and
- This trial incorporated a cultural monitoring plan (Rangitāne o Manawatū Cultural Values Assessments and Cultural Monitoring) alongside the Western science that was facilitated by a representative from Tanenuiarangi Manawatū Incorporated (TMI, Siobhan Lynch-Karaitiana), the outcomes of which are presented in Appendix A.

Results

- Results indicate that both chemical (trace metal) and microbial (*E. coli*) contaminants are reduced to below guideline levels (Grade Ab, NZWWA, 2003) within six months of establishment through dilution and composting processes;
- Composting reduced the moisture content of the initial product which can make transport of the material easier due to improved handling;
- Results from analysis of *E. coli*, ammonium-N and DHA indicated that the sludge compost was sufficiently stabilised after six months;
- Based on analysis of phosphorus, organic-N ammonium-N and nitrate-N it is evident that all 12 sludge composts would provide adequate short-term and long-term nutrition for use as a soil conditioner or plant amendment;
- Elevated trace metals (Zn) in some final composts was a result of reduction in total volume of the product through natural processes, and indicates initial dilution ratios need to take this into account when dealing with metal containing sludges;
    - These levels were such that the compost could be bought below 'grade Aa' limits if all 12 were mixed together; and

- Significant insight into local iwi views and the cultural effects of biosolids composting at Awapuni Resource Recovery Centre was gained through the production of a cultural impact assessment (CIA) by Te Ao Turoa Environmental Centre (TATEC) researchers that indicated:
    - Beneficial use of biosolids is viewed positively;
    - Landfilling of biosolids was strongly rejected;
    - It is important that biosolids are not applied around waterways and wahi tapu;
    - The most supported options for use were non-food producing locations such as forestry or biodiversity regeneration/restoration; and
    - Whilst composting was viewed positively, it did not significantly alter the participants views on acceptable use options.

Conclusions

This trial aimed to investigate the practical and/or technical viability of sludge composting by way of a large-scale field trial. In particular, it set out to test the hypothesis that irrespective of sludge source the quality of the final product was similar; meaning that a consistent compositing approach could be used for a range of sludge sources and generate a similar end product.

The composting process stabilised microbial contaminants and effectively diluted chemical contaminants to produce a product that met guidelines for composts in NZ (NZS4454, 2005) and 'Grade Aa' and/or 'Grade Ab' biosolids (NZWWA, 2003). This was evident in all three contrasting sludge products used for this trial; suggesting that, excluding high levels of chemical contaminants, the sludge used in the initial feedstock had little effect on the quality of the final product.

Based on the results of this trial it is suggested that commercial composting, under optimal conditions and following recommended procedures, is a viable means of producing a material suitable for a wide range of end uses which might otherwise not be available to un-composted WWTP sludge.

2 INTRODUCTION

2.1 Background

More than 320,000 tonnes of wastewater treatment plant solids (sewage sludge) are produced every year in New Zealand. Most of this sludge ends up in landfills, not considered a long-term management option due to increased levies, space requirements and transportation distances. In addition, Government policy and community expectations now focus on the development of sustainable use options.

The MfE Waste Minimisation funded project "Collective Biosolids Strategy – Lower North Island" is taking a collaborative approach to the issue of sludge management. Together with the Project Team (Lowe Environmental Impact (LEI), Massey University and Institute of Environmental Science and Research Ltd (ESR)) a collective of nine New Zealand territorial authorities are working in partnership to develop a regional biosolids strategy with a focus on beneficial end-use. The project focuses on smaller councils that may otherwise be unable to fund such investigations and/or solutions individually. The outcome of the project aims to provide a 'toolbox' of different scenarios in the form of a model of operation that can be applied in other regions around New Zealand.

The Project Team have organised the work into project Activities and Tasks. One of which is Activity 1: Biosolids Processing Trials; testing the feasibility of a selection of potential end-use options through on ground application (research trials) and desktop feasibility/cost analysis. The three research trials completed are:

- A large-scale biosolids/sludge composting trial;
- In laboratory testing of the feasibility of using biosolids/sludge in seedling growth media; and
- A grazing crop field trial using oats, Italian ryegrass and pasture.

This report outlines the results of the biosolids composting trial carried out at the Palmerston North City Council Resource Recovery Centre and aims to confirm the practical and/or technical viability of composting biosolids currently being sent to landfill.

As part of the strategy development Council Partners expressed interest in better understanding the potential end-use options for biosolids in their region. There are several options for reuse of biosolids within the lower North Island and many promote sustainable waste management and support Government strategies. These options include:

- Forestry (natives and exotics);
- Agriculture and horticulture;
- Municipal Landscaping;
- Land rehabilitation;
- Road Corridors;
- Landfill capping;
- Arboriculturists (tree and shrub nurseries); and
- Commercial enterprise (i.e. commercial composting).

Palmerston North City Council (PNCC) and Manawatu District Council (MDC) are already investigating and/or putting into practice composting as a process to improve the quality of their sludge. Improvements to sludge quality allow for a wider range of end-use options (Reports 4 and 14) based on restriction outlined in the 'biosolids guidelines' and relevant 'Regional Plans'.

Composting is a process in which organic solid matter is biodegraded under aerobic conditions to produce an organic amendment with nutritional value to soil (Haug, 1993).

2.2 Scope

The Project Partners agreed to investigate the practical and/or technical viability of sludge composting by way of a large-scale field trial blending three different sludges/biosolids with green waste and composting. The aim was to determine if a high-quality compost product could be produced from varying mixtures of contrasting sludge, and if using a common process with different sludges resulted in products of differing quality.

In addition, recognising the importance of incorporating iwi values into issues on wastewater management the project team sought to compliment the trials western science through engagement with local iwi. As part of this the opportunity was presented to representatives of Rangitāne o Mananwatū (RoM) to participate in the establishment of the biosolids composting trial at PNCC, and feed into the Collective Biosolids Strategy. Te Ao Turoa Environmental Centre (TATEC) researchers assessed the cultural effects of biosolids composting, and high-level considerations for beneficial re-use within the Rangitāne o Manawatū area of interest through the production of a cultural impact assessment (CIA). 'Live' case studies such as this give a practical context to ensure that science research is relevant, meaningful and appropriate to community needs.

The purpose of this report is to outline the trial methods and processes and present the trial results.

2.3 Terminology

Biosolids and sludges. The quality of wastewater solids (ww solids) is highly variable, ranging from raw sludge to more processed sludges which are termed 'biosolids'. The broad term ww solids refers to the solid waste produced as a by-product of municipal wastewater treatment (sewage sludge). The 'Guidelines for the Safe Application of Biosolids to Land' define Biosolids as sewage sludges (or sewage sludges mixed with other materials) that have been treated and/or stabilised to the extent that they are able to be safely and beneficially applied to land (NZWWA, 2003). This determination is based on criteria outlined within the guidelines. The terminology used in this report defines biosolids and sludges according to these criteria.

Composting process. A method whereby organic materials are transformed through microbial processes, under thermophilic aerobic conditions. Ordinarily takes place at temperatures of >55°C due to heat released by biochemical transformations. Composting processes must achieve time-temperature requirements as specified in NZS 4454:2005 for pasteurisation, stability and maturity.

Compost. Organic matter that has undergone controlled aerobic composting to achieve pasteurisation, stability and maturity, and complies with appropriate criteria according the NZ Standard for Composts, Soil Conditioners and Mulches (NZS 4454, 2005: Table 3.1).

Maturation. The biodegradation of organic material (i.e. sludges and biosolids) to substances that are similar to soil humus and that are determined to be safe for use with plants (based on criteria set out in NZS4454, 2005 & NZWWA, 2003). A 'mature' compost is one that is determined to be significantly decomposed and which will not cause harm to plants if used as an amendment.

Nitrification. The biological oxidation of ammonium to nitrite followed by the oxidation of the nitrite to nitrate.

Green waste. Green waste is described as materials derived from commercial or domestic gardening activities and may include: tree and shrub prunings, leaves, branches and other woody and non-woody materials. For the purpose of this trial green waste is shredded and does not contain grass clippings.

Windrow. A long row or pile of organic material to be composted. Usually 1.5 - 3 m high and consisting of a mixture of biodegradable waste, such as animal manure and green waste.

2.4 Biosolids and Sludge as Soil Conditioners

Biosolids and sludges are carbon-rich and contain high concentrations of valuable nutrients (N, P, trace elements) that can have high fertiliser value, especially in degraded environments. However, as a by-product of human excreta both can be a vehicle for numerous contaminants (such as heavy metals, and human pathogens). While these characteristics present challenges, the waste material also offers opportunities for re-use. Through stabilisation processes it is possible to yield products that are considered safe for re-use on land (i.e. Biosolids Grade Bb-Aa, NZWWA, 2003) and that can improve soil productivity. One means to achieve this is through commercial composting, which has been shown to effectively transform organic waste into useful nutrient containing soil amendments.

3 TRIAL SET UP

3.1 Composting Process

There are three main types of common composting that can be used for organic materials:

- Windrows;
- Aerated static piles; and
- In-vessel systems.

For this trial composting was carried out using a windrow system whereby sludge mixtures were placed in long rows and turned periodically to reduce moisture levels, improves oxygen flow and maintain even temperatures.

Under these types of systems, composting of sludges involves the mixing with a co-product such as green waste to provide a source of carbon and improve oxygen flow (porosity) within the pile. Through the composting process and subsequent biological activity heat is generated, destroying pathogens and aiding in nutrient cycling (mineralisation and nitrification).

3.2 Location

The biosolids composting trial was set up at the PNCC Awapuni composting site (Awapuni resource recovery centre, figure 3.2.1), Tip Road, Palmerston North. The Awapuni composting facility routinely composts digester sludge from the Palmerston North WWTP, mixing the sludge with shredded green waste dropped off by the local community. The sludge is currently composted in large windrows and retained on site for one year (as per current resource consents) before being used to cap the decommissioned Awapuni landfill.

A section of the composting site was made available for the trial away from both the commercial composting operation (non-sludge containing compost) and the routine sludge composting. The site was such that it would not be affected by run-off from other windrows and contamination between the trial and routine composting would be minimised.

Figure 3.2.1 The Awapuni Resource Recovery Centre, Tip Road, Palmerston North.

3.3 Experimental Design

Twelve compost piles (windrows) of mixed sludge and green waste were established at the Awapuni composting site, containing mixtures of three locally sourced sewage sludge as follows:

- Palmerston North WWTP digester sludge;
- Palmerston North WWTP alum sludge; and
- Bunnythorpe oxidation pond sludge.

The combination of sludge and green waste were mixed at a ratio of 1:4 (approx.) as outlined in Table 3.3.1. The final volumes of sludge/green waste used was based on the amount required to achieve manageable windrows, required temperatures for composting and to allow for shrinking of the piles.

Table 3.3.1 Sludge and compost ratios for the twelve compost piles – PN Composting trial

Treatment number	Description	Volumes	Date of Establishment
1	Bunnythorpe pond sludge + green waste rep a	48 m^3 Bunnythorpe pond sludge 189 m^3 green waste	29/03/2019
2	Bunnythorpe pond sludge + green waste rep b	48 m^3 Bunnythorpe pond sludge 189 m^3 green waste	04/04/2019
3	PNCC alum sludge + green waste rep a	48 m^3 PNCC alum sludge 189 m^3 green waste	11/02/2019
4	PNCC alum sludge + green waste rep b	48 m^3 PNCC alum sludge 189 m^3 green waste	14/02/2019
5	PNCC digester sludge + green waste rep a	48 m^3 PNCC digester sludge 189 m^3 green waste	04/02/2019
6	PNCC digester sludge + green waste rep b	48 m^3 PNCC digester sludge 189 m^3 green waste	07/02/2019
7	Bunnythorpe pond sludge + PNCC alum sludge + green waste rep a	24 m^3 Bunnythorpe pond sludge + 24 m^3 PNCC alum sludge 189 m^3 green waste	09/04/2019
8	Bunnythorpe pond sludge + PNCC alum sludge + green waste rep b	24 m^3 Bunnythorpe pond sludge + 24 m^3 PNCC alum sludge 189 m^3 green waste	10/04/2019
9	PNCC digester sludge + Bunnythorpe pond sludge + green waste rep a	24 m^3 PNCC digester sludge + 24 m^3 Bunnythorpe pond sludge + 189 m^3 green waste	11/04/2019
10	PNCC digester sludge + Bunnythorpe pond sludge + green waste rep b	24 m^3 PNCC digester sludge + 24 m^3 Bunnythorpe pond sludge 189 m^3 green waste	12/04/2019
11	PNCC alum sludge + PNCC digester sludge + green waste rep a	24 m^3 PNCC alum sludge + 24 m^3 PNCC digester sludge 189 m^3 green waste	25/02/2019
12	PNCC alum sludge + PNCC digester sludge + green waste rep b	24 m^3 PNCC alum sludge + 24 m^3 PNCC digester sludge 189 m^3 green waste	04/03/2019

3.4 Windrow establishment

Establishment of the 12 compost windrows occurred throughout February to April, 2019. Not all windrows were established at the same time due to sourcing issues relating to the extraction and drying of sufficient oxidation pond sludge for the trial. The date of establishment of each windrow is shown in Table 3.3.1.

During formation of the windrows all materials were treated the same. Each windrow required 6 ‘truckloads’ of sludge (approximately 8 m^3 each) mixed by front end loader with 54 ‘heaped buckets’ (approximately 3.5 m^3 each) of shredded green waste. The final volumes were estimated to be 237 m^3 of material in each windrow (1:4 ratio of sludge to green waste) forming a 12 m long pile.

The process of windrow formation and the sludge consistency can be seen in Figures 3.4.1 – 3.4.4. The location of each windrow on site is visible in Figure 3.4.4. Detailed photographs of individual rows were taken at each monthly sampling, some of which can be seen in Section 4.3.

Figure 3.4.1. A front-end loader mixing green waste for windrow 6 (WWTP digested sludge with green waste) in February 2019.

Figure 3.4.2. Bunnythorpe oxidation pond sludge next to green waste prior to mixing.

Figure 3.4.3. LEI scientist Eise Venter standing on a 12 m long compost windrow.

Figure 3.4.4. A Google Earth satellite image of Awapuni composting site showing the final location of the 12 biosolids composting trial windrows. The trial site is elevated and can be seen to be separate from existing composting activities.

4 MONITORING AND ANALYSIS

4.1 Compost and Sludge Sampling Procedures

Obtaining a representative sample is critical as sludge and compost can be highly variable. Sampling procedures are outlined in the Guidelines for the safe application of biosolids to land in New Zealand (NZWWA, 2003); Volume 2: Technical Manual, Section 9, and were used as the basis for sampling.

Sampling was carried out by LEI on windrow establishment (baseline) and subsequently on a monthly basis. Just prior to arrival on site, PNCC personnel removed the 4 corners of each windrow using a front-end loader (Figure 4.7) to allow for access to the deeper sections of the compost and obtain a representative sample.

Once on-site LEI personnel took photos of each windrow including photos of the sign board (label), open corners and the whole heap (Appendix A).

For each windrow the sampling procedure was as follows. At each of the four opened corners, a hole was dug using a clean/washed stainless steel hand trowel to obtain fresh material. Using the hand trowel 5 – 10 heaped scoops of compost was removed from the hole and put into a lined bucket. Samples from all four corners were combined and mixed to form one composite sample. From this composite sample sub-samples were taken to fill the required analysis containers and placed in a chilly bin containing ice packs. The remining composite sample was discarded back onto the same heap it was sampled from. In between samples hand trowels were washed and gloves/ plastic bucket liner discarded and replaced to prevent cross contamination.

Figure 4.1.1 A Front-end loader is used to remove the four corners of each compost pile to allow for representative samples to be taken.

4.2 Analysis

Baseline samples of compost were analysed for an array of chemical and biological parameters at initial establishment followed by daily/monthly monitoring and a final analysis at the completion of the trial (Table 4.2.1).

Table 4.2.1. Variables to be tested for sludge and green waste samples before, during and after the trial period

Time	Analysis	Samples
Post-mixing /Windrow formation LEI to collect and send	**Send to Watercare - As per Watercare instructions** - *E. coli* - *Salmonella* - *Campylobacter* - Helminths *(will not measure at the end if no ova are present)* - Total Cu, Zn, As, Cd, Cr, Pb, Mg, Ni, - Organic Matter, Dry Matter, Ash, Volatile Solids, Phosphorus, pH - Ammonium-N, Nitrite-N, Nitrate-N, Nitrate-N + Nitrite-N, Total Carbon **Send to ESR Kenepuru – Jo Hewitt** *Adenovirus (will not measure at the end if no virus is present)* **Send to ESR Kenepuru - (20g approx.)** Dehydrogenase enzyme and moisture content	12 x windrows (composite samples immediately after formation) **Total samples – 12**
Daily or as able PNCC to carry out	**PNCC** Temperature	12 x windrows **Total samples – 12**
Monthly LEI to collect and send	**Send to ESR Kenepuru – Izzy Alterton (20g approx. on ice but not frozen)** Dehydrogenase enzyme and moisture content	12 x windrows **Total samples – 12**

Time	Analysis	Samples
Six months post establishment LEI to collect and send	**Send to Watercare – As per Watercare instructions** - *E. coli* - *Salmonella* - *Campylobacter* - Total Cu, Zn, As, Cd, Cr, Pb, Mg, Ni, - Organic Matter, Dry Matter, Ash, Volatile Solids, Phosphorus, pH - Total Nitrogen, Ammonium-N, Nitrite-N, Nitrate-N, Nitrate-N + Nitrite-N, Total Carbon **Send to ESR Kenepuru (20g approx.)** Dehydrogenase enzyme and moisture content	12 x windrows **Total samples – 12**

4.2.1 Baseline Analysis

Samples from each windrow were analysed upon establishment for a range of baseline parameters (Table 3.2.2). Samples were taken by LEI staff according to sampling procedures outlined in section 4.1 and distributed as follows:

Watercare (Auckland):

- *E. coli;*
- *Salmonella;*
- *Campylobacter;*
- Helminths;
- Total recoverable Cu, Zn, As, Cd, Cr, Pb, Mg, Ni, P;
- pH;
- Total carbon and organic carbon;
- Total, and volatile solids; and
- Ammonium-N, Nitrite-N, Nitrate-N and Nitrate-N + Nitrite-N;

ESR Ltd, Kenepuru.

- *Adenovirus*
- Dehydrogenase enzyme activity
- Moisture content

Methods for biochemical, chemical and biological analysis are outlined in section 4.4.

4.2.2 Monthly Analysis

Samples were analysed monthly for parameters chosen to reflect the progress of the composting process. At each monthly sampling compost samples were transported and refrigerated at LEI Palmerston North offices and subsequently couriered in chilly bins with ice packs to the relevant laboratory within 24 hours as follows:

ESR Ltd (Kenepuru) - Dehydrogenase enzyme activity (DHA) and moisture content

Watercare – *E. coli* (mpn), nitrate-N and ammonium-N

Daily temperature readings were taken by staff at the Awapuni composting site using a standard Teltherm Composting temperature probe and recorded for reference.

Further method details can be found in section 4.3.

4.2.3 Six-Month Analysis

The compost from each windrow was analysed for a range of parameters after six months to determine the completion of the composting process. The analysis undertaken were a repeat of those carried out at the baseline sampling (Section 4.2.1), with the addition of total nitrogen (TN).

4.3 Methods

4.3.1 Watercare Laboratory Services - Methods

Soil biological, and chemical analysis was carried out by Watercare Laboratory Services (Auckland, NZ) according to the methods outlined in Table 4.3.1. For further details of these methods refer to Watercare, NZ.

Table 4.3.1 Watercare Laboratory Services (Auckland, NZ) testing methods

Analyte	Reference Method
Chemistry	
Total Carbon (% wt/wt)	USEPA NCEA-C-1282 (Modified).
Total Organic Carbon (%)	USEPA NCEA-C-1282 (Modified).
Recoverable Ammonium-N (mg/kg dw)	Potassium Chloride Extraction and Flow Injection Analysis, APHA (online edition) 4500-NH3 H.
Recoverable Nitrite-N (mg/kg dw)	APHA (online edition) 4500-NO2 I (modified).
Recoverable Nitrate-N (mg/kg dw)	By calculation, Nitrate-N Calculation: (Nitrate-N + Nitrite-N) - Nitrite-N. (recoverable dw)
Total Oxidised Nitrogen (mg/kg dw)	By Potassium Chloride Extraction and Flow Analysis, APHA (online edition) 4500-NO3 I. (recoverable dw)
Total Nitrogen (%)	By Non-dispersive infrared detection.
pH	By electrode, Soil Sampling and Methods of Analysis. Can. Soc. Soil Sci. (2008)
Total Solids (%)	APHA (online edition) 2540 G
Volatile Solids (%)	APHA (online edition) 2540 G
Recoverable metals: Cu, Zn, As, Cd, Cr, Pb, Mg, Ni, P (mg/kg)	APHA (online edition) 3125 B by ICPMS
Microbiology	
Thermotolerant *Campylobacter* (MPN/g)	In-house based on MIMM 13.1
Escherichia coli (MPN/g)	5-tube MPN utilising Lauryl Tryptose Broth based on Part 9221 MPN of APHA (2005)
Salmonella (MPN/g)	5-tube MPN with Selenite Cystine and Rapport Vassiliadis Soya Medium (R.V.S.) selective broths based on MIMM, 2004, Chapter 13.2
Helminth ova	Horizontal - WP3

4.3.2 Environmental Science and Research (ESR) Methods

Within 48 hrs of sample collection, samples were analysed for moisture content and dehydrogenase activity (DHA) according to methods outlined below.

Moisture Content
Moisture was determined by loss of weight of the homogenised fresh sample after drying at 104 °C for 24 hrs.

Dehydrogenase activity
Dehydrogenase activity was determined by the reduction of 2,3,5 – triphenyltetrazolium chloride (TTC) to triphenylformazan (TPF) as described in Wong and Fang, 2000 and Barrena et al. 2008. Results were expressed in DHA (mg TPF kg^{-1} hr^{-1}) on a dry weight basis.

Culturable Adenovirus
Culturable adenovirus was determined by culture-qPCR using 293 cells with culture-PCR. The minimum detection of culturable adenovirus is 1 infectious units (IU)/2.5 g.

4.4 Data Analysis

Microsoft Excel was used to determine means and standard errors of biochemical data.

4.5 Rangitāne o Manawatū Cultural Values Assessments and Cultural Monitoring

The PNCC composting trial incorporated plans for in-depth cultural values assessments and cultural monitoring (Te Ao Turoa Environmental Centre Cultural Impact Assessment; Appendix B) to run alongside the western science facilitated by LEI, Massey University and ESR. The final plan was administered by a representative from Tanenuiarangi Manawatū Incorporated (TMI, Siobhan Karaitiana) and took the form of a cultural impact assessment (CIA). Siobhan Karaitiana investigated cultural values and viewpoints associated with the composting of biosolids by carrying out interviews with members of Rangitāne o Manawatū. Further information on the TMI cultural impact assessment are presented in Section 6 with the full report available in Appendix B.

5 RESULTS AND DISCUSSION

5.1 Baseline Sampling

Results from the baseline compost sampling can be seen in Table 5.1.1. Each sample was taken on windrow establishment and sent to the relevant laboratory for analysis (section 4.2). The results for each analysis are compared against the current New Zealand Biosolids Guidelines (NZWWA, 2003). A biosolids product that has very low levels of contaminants (heavy metals and microbial contaminants) and is able to be safely handled by the public is designated as Grade Aa. A biosolids product that has higher levels of contaminants but is able to be safely applied to land under certain conditions, is designated Grade Bb. A biosolids product that exceeds Grade Bb limits is not considered safe for use in its present state and requires further stabilisation (sludge).

Under the criteria set out in the biosolids guidelines (NZWWA, 2003) 11 of the 12 windrow treatments exceeded Grade A limits for *E. coli* (< 100 MPN/g) and would therefore be considered Grade B for stabilisation. One windrow had levels greater than guideline limits for *Salmonella* (<1 MPN/25g, windrow 1). No other microbial indicator organisms or pathogens measured (*Salmonella*, *Campylobacter*, helminth and adenovirus) were found to exceed acceptable levels.

Only one windrow exceeded 'Grade a' levels for trace metal contaminants (Zn and Cu in windrow 12) whilst one further windrow (windrow 8: Pond sludge + PNCC alum sludge + green waste) exceeded 'Grade b' limits for As, making this treatment less than Grade Bb and therefore not considered suitable for land application at the beginning of the trial. Whilst the sampling regime undertaken was robust, the green waste cannot be excluded as the source of As in this sample.

It should also be noted that baseline compost samples were taken after mixing biosolids with green waste (1:4 ratio of sludge to green waste) and therefore concentrations/levels of contaminants have been diluted. It can be assumed that levels would be up to four times greater in the original sludges, in many cases exceeding Grade Bb for As.

Table 5.1.1. Baseline results for 12 windrows of Palmerston North sewage sludge mixed with green waste.

		Treatment											
Parameter	Unit	1	2	3	4	5	6	7	8	9	10	11	12
Nitrate-N	mg/kg	4.9	0.75	0.2	1.9	5.4	0.42	7.4	3.7	23	5.8	1.2	1
Nitrite-N	mg/kg	0.26	0.78	0.51	0.62	8	1.2	5.3	1.9	2	4.6	0.75	0.63
pH	pH unit	7.3	6.7	7	7.5	7.6	7.5	7.6	8.2	8	8	8.4	8.3
Ammonium -N	mg/kg	600	1100	2000	2000	1600	1200	3500	1300	3400	2000	2200	2000
Total C	% wt/wt	11	21	23	22	23	23	17	24	26	23	21	28
Total organic C	% wt/wt	9.9	18	23	21	22	22	15	24	26	22	17	20
Total oxidised N	mg/kg	5.2	1.5	0.71	2.5	13	1.6	13	5.6	35	10	2	1.7
Total P	%	0.24	0.22	0.49	0.59	0.33	0.33	1.1	0.47	0.73	0.37	0.65	1.2
Total solids	%	86	66.5	58.1	50.3	55.8	55.4	36.7	55.2	35.9	45.4	62.8	63.4
Voltile solids (OM)	%	54	40.7	59.8	62.4	47.4	46.5	49.4	22.8	54.8	44.3	52.1	52.8
As	mg/kg	7.2	8.5	10	12	12	12	7.9	54**	6.5	9.2	18	7.2
Cd	mg/kg	<0.45	0.46	<0.45	<0.45	<0.45	<0.46	<0.45	<0.44	0.48	<0.45	0.46	0.66
Cr	mg/kg	9.9	12	11	12	13	14	11	89	13	13	24	17
Cu	mg/kg	31	38	32	38	34	41	49	69	68	57	52	110*
Pb	mg/kg	48	48	84	72	56	46	42	35	44	47	54	50
Mg	mg/kg	2000	2300	2300	2500	2800	2800	2100	2000	2300	2300	3500	2600
Ni	mg/kg	6.5	5.3	4.5	4.8	6.8	6	4.5	5.1	6.2	5.5	14	9.7
Zn	mg/kg	200	250	190	210	210	210	220	180	370*	250	270	490*
E.coli	MPN/g	>190000*	740*	140*	>320000*	>290000*	>290000*	250000*	98000*	6200*	730*	11	630*
Salmonella	MPN/g	>1.3*	<0.023	<0.026	<0.03	<0.027	0.64	<0.041	<0.027	<0.041	<0.033	<0.024	0.34
Campylobacter	MPN/g	<0.015	<0.019	<0.022	<0.025	<0.022	<0.023	<0.037	<0.022	<0.034	<0.028	<0.02	<0.02
Helminth	/4g	<0.47	<1.0	0.69	0.8	<0.72	0.72	0.91	1	1.8	2	<0.64	<0.63
DHA	mg TPF kg^{-1} hr^{-1}	43.53	18.22	0.65	1	0.78	0.86	16.4	21.3	17.7	27.2	3.11	7.85
Adenovirus	/2.5g dw	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

*value exceeds grade "Aa" and ** grade "Bb" biosolids

Treatments: 1 & 2. Pond sludge + green waste, 3 & 4. Alum sludge + green waste, 5 & 6. Digester sludge + green waste 7 & 8. Pond sludge + Alum sludge + green waste, 9 & 10. Digester sludge + Pond sludge + green waste, 11 & 12. Alum sludge + Digester sludge + green waste

5.2 Monthly Analysis

5.2.1 Length of monitoring

Due to variations in the establishment date between treatments the total period of monitoring was not the same for all windrows (Table 5.2.1), however 'final' analysis samples were taken for each windrow at the 6-month mark to assess the effectivity of the composting.

Table 5.2.1. Monitoring duration of the composting piles

Composting piles	Duration (weeks)
1	33
2	31
3, 4, 5, and 6	40
7, 8, 9, and 10	28
11 and 12	31

5.2.2 Dehydrogenase activity

Dehydrogenase activity (DHA) in soils and other biological systems is frequently used as a measure of overall microbial activity since these enzymes only function intracellularly, and not freely in soil (Prosser et al., 2011; Barrena et al., 2008). Previous research has shown that DHA can be used to monitor the biological activity of the composting process (Wong and Fang, 2000; Barrena et al., 2018). In this field trial we used DHA as a measure of the composting process carried out by microbes. Results for the monthly analysis can be seen in Figures 5.2.2 and 5.2.3.

DHA activity for most of the compost piles was initially low with subsequent fluctuating levels in the middle stage of the monitoring, consistent with expected fluctuations (i.e. spikes) in available N from sludge which increases microbial activity.

The final DHA activity in all 12 windrows reduced to either near or below their initial levels, with all piles relatively stable below their peak activity (Figure 5.2.2). This is an indication that the piles reached the maturation phase of the composting process (Barrena et al, 2008; Wong and Fang, 2000).

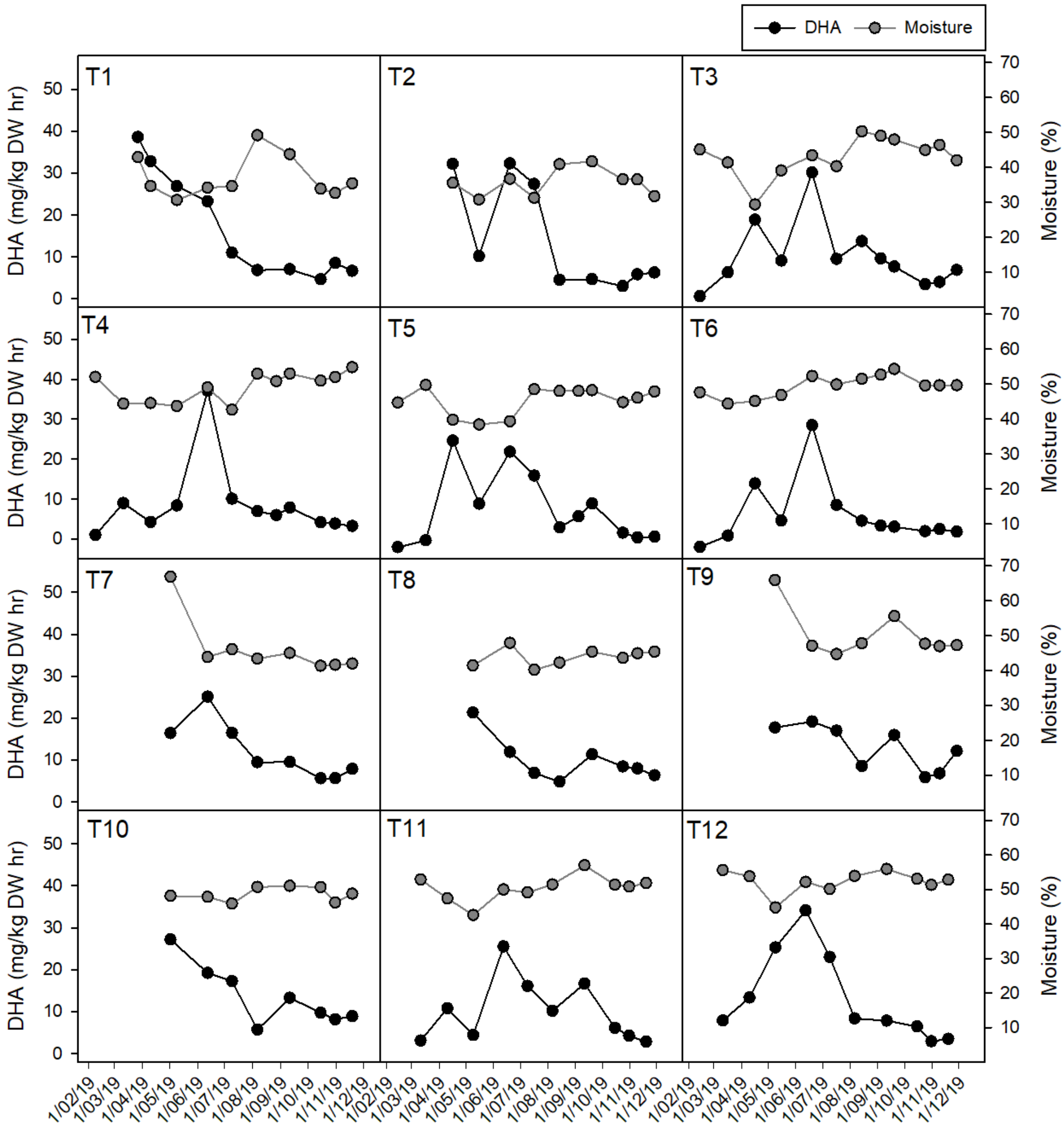

Figure 5.2.2. Dehydrogenase activity of the 12 sludge/green waste compost windrows from February to November 2019.

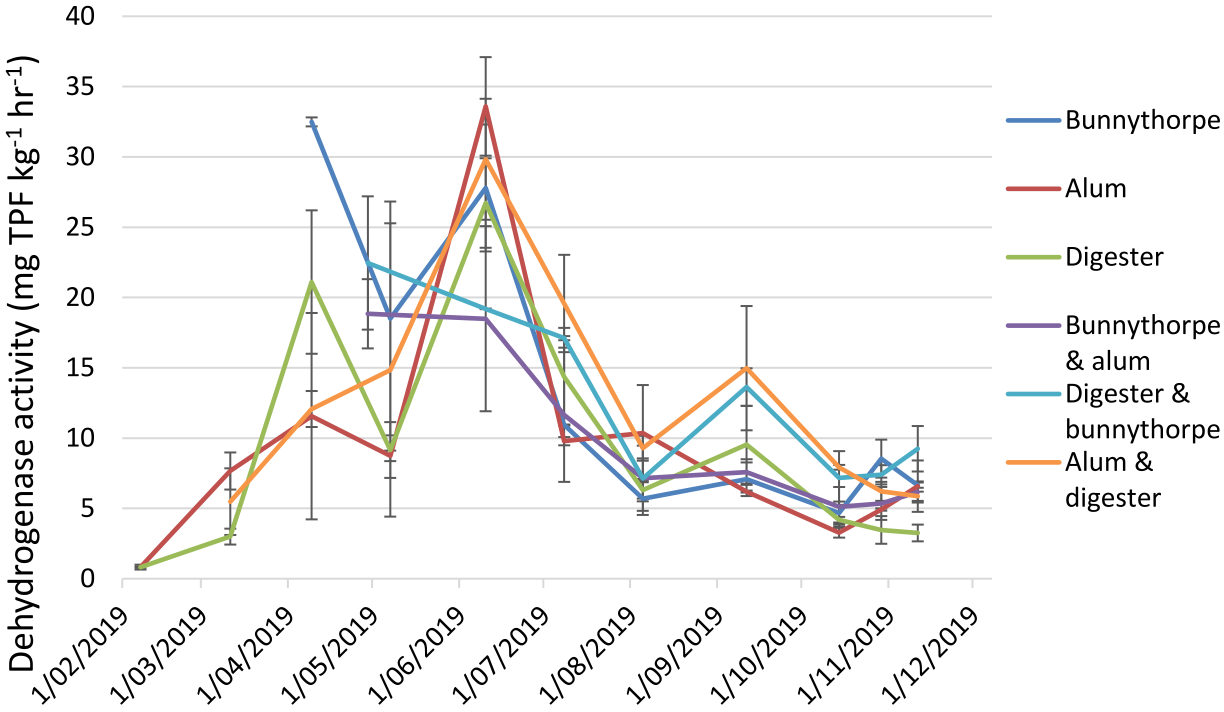

Figure 5.2.3. Average deydrogenase activity for six contrasting sludge/green waste mixtures over time. Error bars represent standard error (SEM)

5.2.3 Moisture

The moisture (Figs 5.2.2 and 5.2.4) varied among treatments with some windrows exhibiting moisture ranging from approximately 40% to 55% (T4, T5, T6, T8, T10, T11, T12) whilst others within the range of 30% to 50% (T1, T2, and T3). While some differences were observed (T7 and T9 have uniquely higher moisture at the beginning, 67.8 % and 65.9 % respectively) moisture content of the piles was considered to be fairly consistent throughout, and in some cases below the optimum range for a turned composting (45 – 65%: NZS 4454, 2005). Whilst lower moisture is considered to be better than too moist (which can cause odour, slow processing, lower temperatures and increased pathogen survival), too low a moisture content can minimise evaporative cooling and therefore increase compost temperatures (overheating) and/or inhibit microbiological activity (NZS 4454).

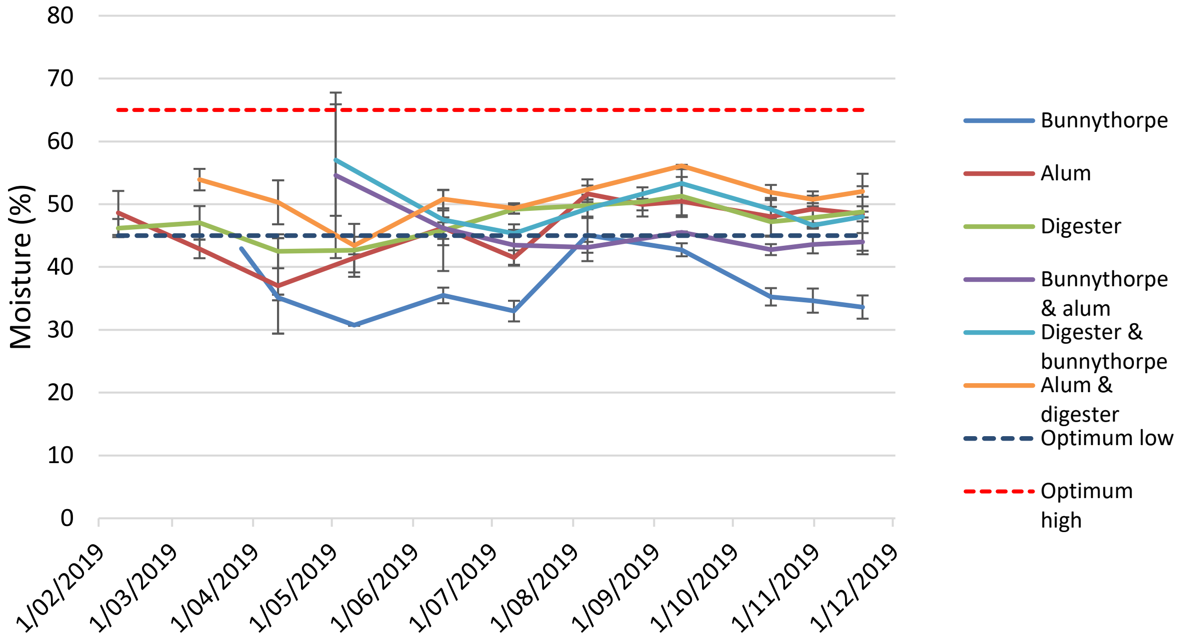

Figure 5.2.4. Moisture content (%) for six contrasting sludge/green waste mixtures over time. Error bars represent standard error (SEM)

5.2.4 Temperature

Temperature is critical to achieving adequate composting, in particular a high temperature is sought in order to remove pathogenic organisms. For pasteurisation of pathogens it is recommended that the compost be maintained at a temperature of ≥ 55°C for at least 15 days with a minimum of 5 turns (NZS 4454, 2005; NZSSS, 2003). When compost temperatures are ≥ 50°C they are determined to have reached the thermophilic phase of composing (Wong and Fang, 2000).

Temperatures of the 12 windrows was recorded throughout the trial and ranged from 42 – 76.6°C, with most windrows above 55°C for all but a few measurements. Initial readings for the pond sludge/green waste windrows from April to May (immediately after establishment) were below this threshold, however all subsequent readings were above.

All except one windrow reached the thermophilic phase within 7 days of establishment, evidence of high levels of microbiological activity. Based on the data in Figure 5.2.5. it can be seen that the compost met relevant criteria for temperature with regards to pasteurisation (NZS4454, 2005). However, temperatures remained high throughout the trial and these did not decline during the testing periods. Though it should be noted that temperatures were only recorded for up to 15 days consecutively starting 1 week after each windrow turn, and temperatures in-between these time are not known. It is usual to observe a decline in temperature due to reduced microbial activity as available nutrients are depleted (NZS 4454), this is considered an indication of the completion of composting. Based on temperature alone it appears that the windrows did not reach maturation phases by the final temperature reading recorded on the 7th August. However, it cannot be determined whether these temperatures declined between then and the final compost sampling on 11th November.

A low moisture content (< 45%) in compost can minimise evaporative cooling and therefore increase compost temperatures (overheating) (NZS 4454). Data presented in Section 5.2.3. indicated that the compost moisture of all 12 windrows was on the low side and in some cases below the optimum moisture range of 45 – 65% (some as low as 30%). This may have resulted in the high compost temperatures observed throughout the trial (Figure 5.2.5).

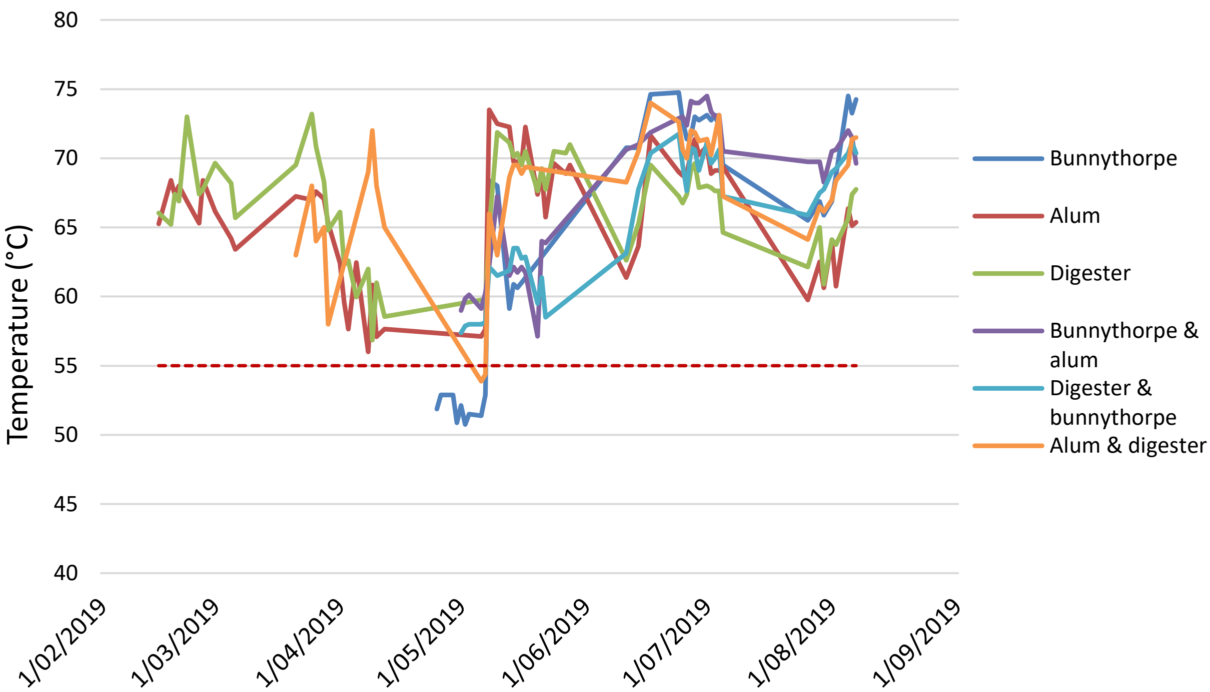

Figure 5.2.5. Average compost temperature (Teltherm composting temperature probe) for six contrasting sludge/green waste mixtures over time.

5.2.5 Escherichia coli

Escherichia coli (E. coli) was monitored as an indicator of the removal of potentially pathogenic organisms in biosolids. As the composting process occurs it is expected that the numbers of *E. coli* will reduce with time through natural attenuation and as an effect of temperature. A biosolids product that has very low levels of microbial contaminants is designated as 'Grade A' (if *E. coli* are < 100 MPN/g) for stabilisation. At these levels compost/biosolids are considered safe for use around people.

Changes in total *E. coli* (MPN) in the six different treatments over the course of the experiment are shown in Figure 5.2.6. The values showed a decline for all the treatments over time, with all except one reducing to below threshold limits of < 100 MPN/g by July 2019, and the remaining treatment achieving this by the next sampling period. For three windrows (8, 9 & 10: see Table 3.2.1) this was achieved after just 10 weeks of composting. This may have also been the case for other treatments but cannot be confirmed due to variation in the selected dates of analysis.

Based on these results all treatments would be considered 'Grade A' for microbial contaminants and stabilisation after 5 months of composting, indicating it would be considered safe for re-use under the NZ biosolids guidelines (NZWWA, 2003).

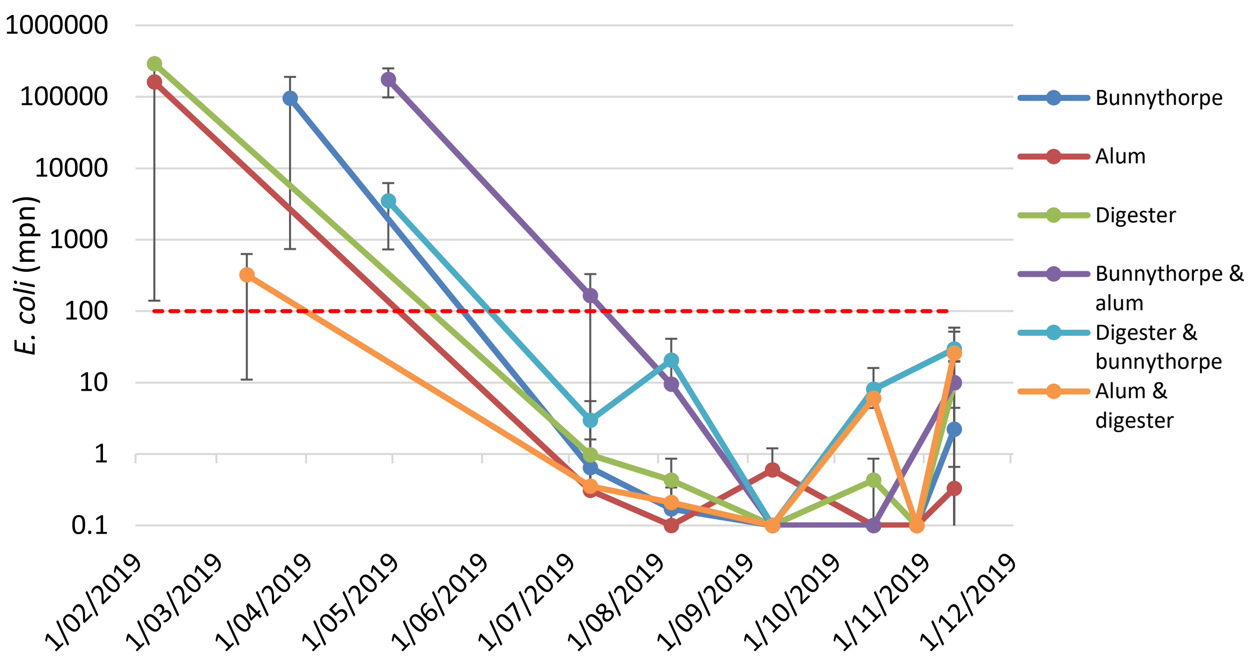

Figure 5.2.6 Average *E coli* (MPN) for six contrasting sludge/green waste mixtures over time. Error bars represent standard error (SEM). Y axis represents log values.

5.2.6 Ammonium-N, Nitrate-N and Nitrite-N

The cycling of N during composting involves complex processes such as volatilisation, nitrification and assimilation. It has been suggested that good determinants for compost maturity and stability are C:N, Ammonium -N (NH_4^+-N) and Nitrate-N (NO_3^--N) concentrations (Bernal et al., 1998; van Schaik et al., 2016).

Throughout composting it is expected that concentrations of NH_4^+-N will decrease from initial levels predominantly via volatilisation and nitrification (Masciandro et al., 2000). A high level of NH_4^+-N in compost material indicates that it is unstable, when the NH_4^+-N concentration decreases and NO_3^--N increases it is considered to have matured/stabilised (Bernal et al., 1998).

It can be seen from Figure 5.2.7 that NH_4^+-N gradually declined in most windrows throughout the trial, with final levels of NH_4^+-N reduced to below initial levels in all but two windrows (windrow 1 & 2). The windrows that did not exhibit such a reduction were those consisting of only Bunnythorpe pond sludge and greenwaste (Figure 5.2.8). These windrows also had lower concentrations of NH_4^+-N at the baseline sampling when compared to the other treatments (Table 5.1), indicating that the aged pond sludge had already achieved some level of stabilisation through natural aging prior to its use in the trial. It should be noted that NH_4^+-N concentrations continued to reduce after the six month 'final' sampling time before appearing to stabilise from September onwards.

The concentration of NO_3^--N in compost over the course of the experiment can be seen in Figure 5.2.9. Initial concentrations of NO_3^--N ranged from 0.2 – 23 mg/kg and increases for a time before appearing to drop. As mentioned, it is typical for NO_3^--N to be lower at the beginning of composting (indicating an immature compost) and increase as the compost matures. A lack of build-up of NH_4^+-N over the course of the experiment and increasing NO_3^--N concentrations suggests favourable nitrifying conditions within the compost (through the conversion of NH_4^+-N to NO_3^-N, Masciandro et al., 2000).

Levels of Nitrite present in the compost followed a similar pattern to that of NO_3^--N, however levels were low, and no accumulation of nitrite was observed over time (Figure 5.2.10). This is consistent with expected composting processes and indicates that adequate oxygen (aerobic conditions) was present in the compost for nitrification to occur (Bernal et al., 1998). An accumulation of nitrite would indicate that anaerobic conditions were present within the piles (NZS4454, 2005) and this was not observed.

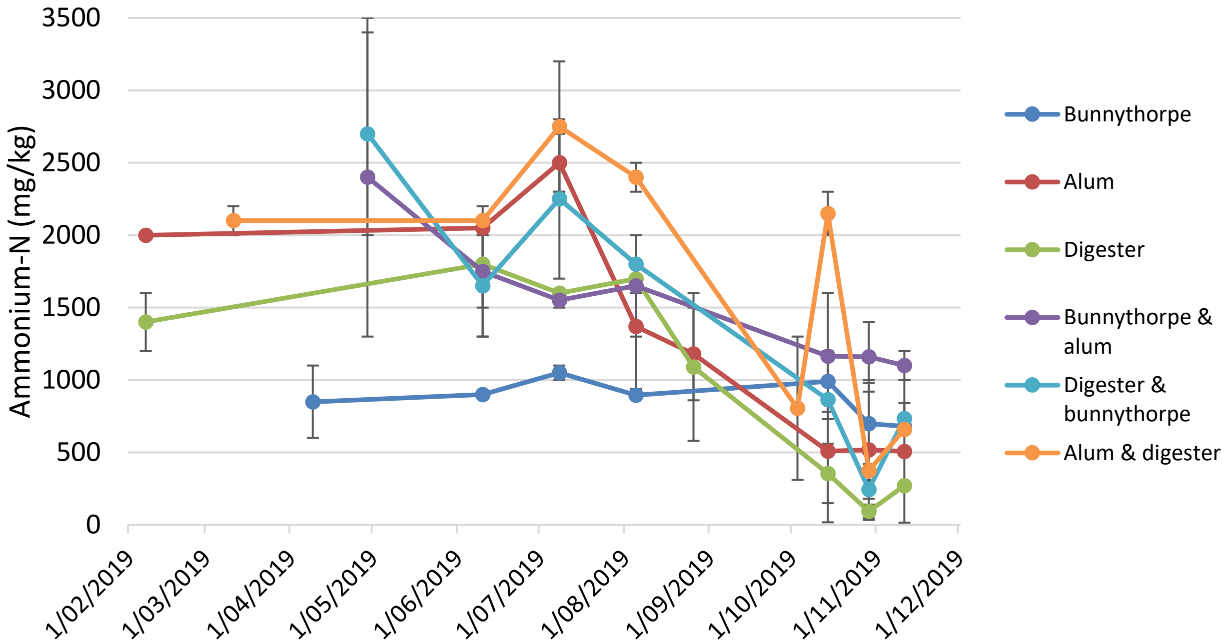

Figure 5.2.7. Average Ammonium-N (mg/kg) for six contrasting sludge/green waste mixtures over time. Error bars represent standard error (SEM).

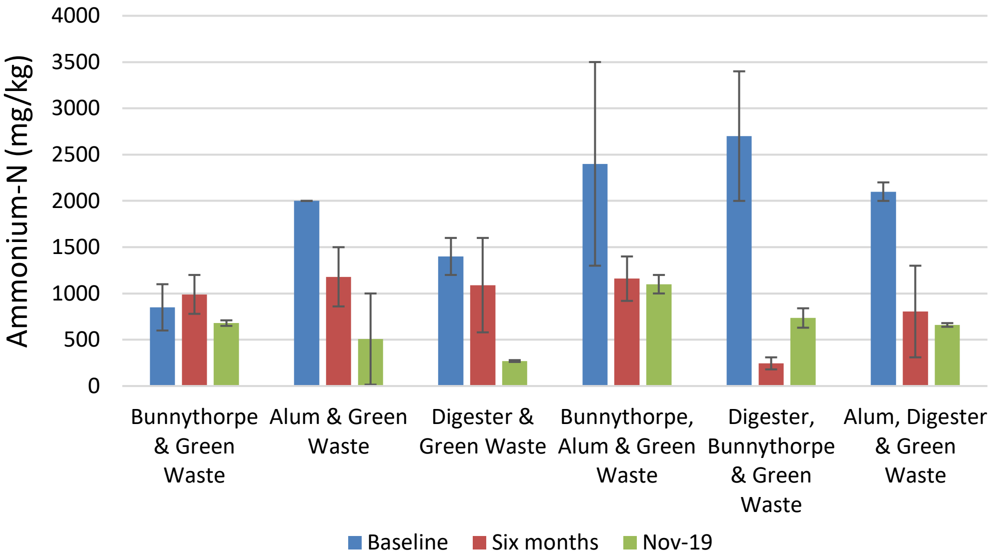

Figure 5.2.8. Average Ammonium-N (mg/kg) for six contrasting sludge/green waste mixtures at initial windrow establishment, after six months of composting and at the final sampling date. Error bars represent standard error (SEM).

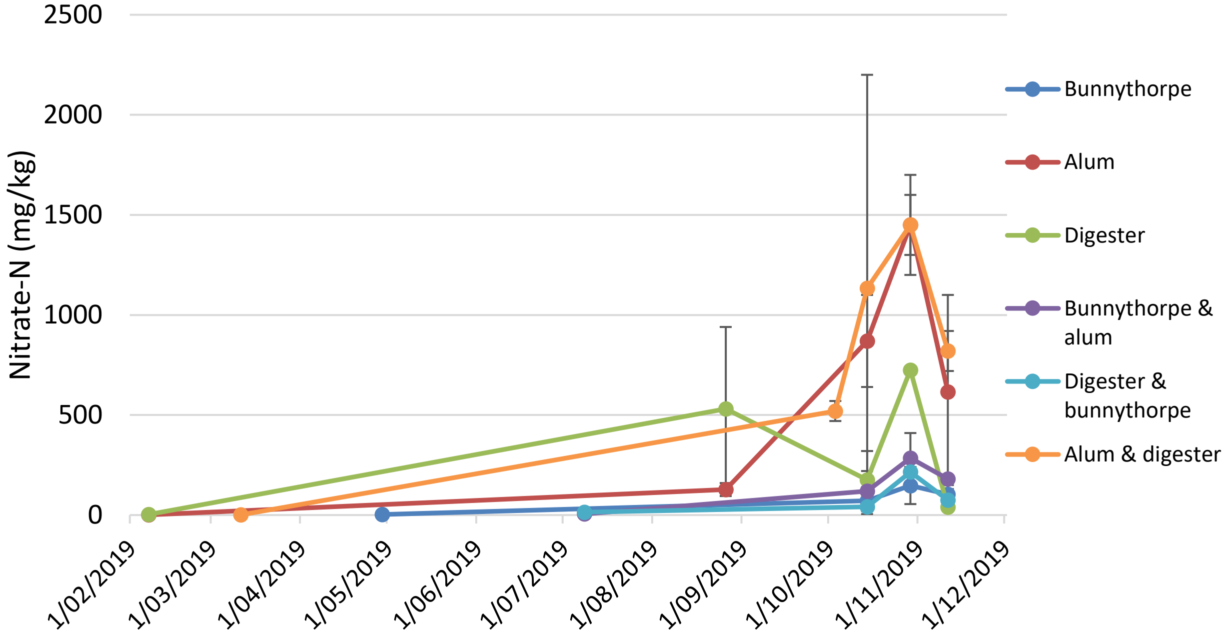

Figure 5.2.9. Average Nitrate-N (mg/kg) for six contrasting sludge/green waste mixtures over time. Error bars represent standard error (SE).

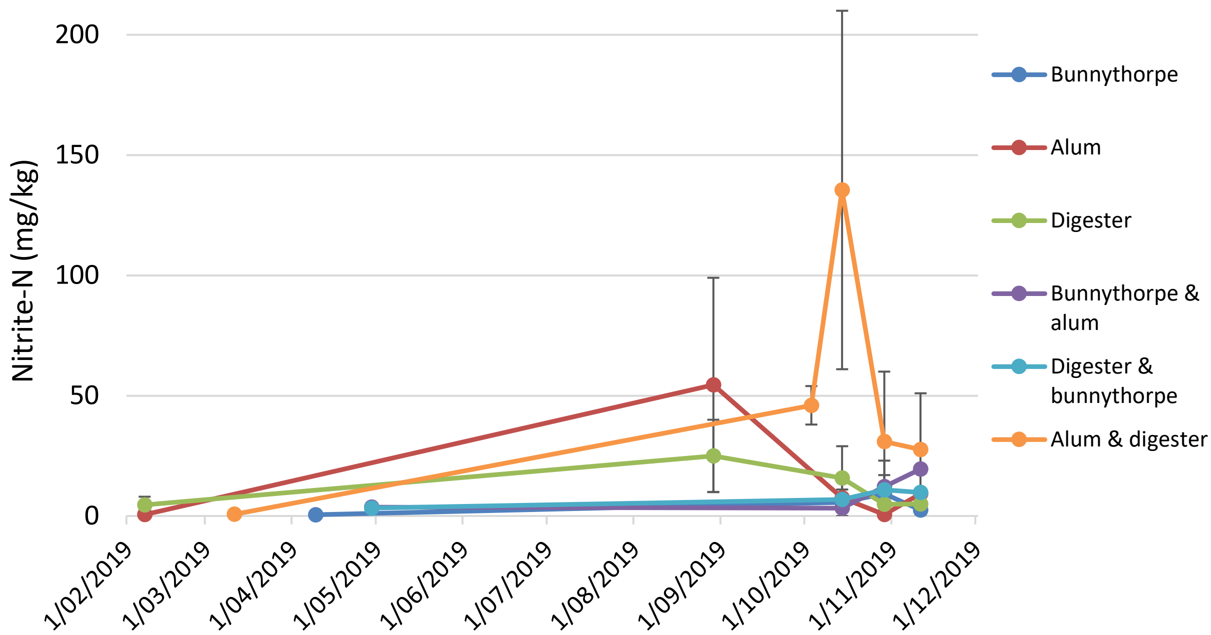

Figure 5.2.10. Average Nitrite-N (mg/kg) for six contrasting sludge/green waste mixtures over time. Error bars represent standard error (SE).

5.3 Six-Month Sampling

In addition to the monthly sampling, the compost from each windrow was analysed for a range of parameters at six months to mark the completion of the composting process. The analysis undertaken were a repeat of those carried out at the baseline sampling (Section 4.2.1), with the addition of total nitrogen (TN). Results from the final sampling can be seen in Table 5.3.1 These results are discussed below.

All 12 windrows were sampled six months after establishment as an 'end point sampling'; however, it is advised to exercise caution when comparing the values between treatments given that each windrow was established at different times. This would have meant that composting occurred over different seasonal fluctuations in rain and temperature which would heavily influence the speed with which the material degraded and the microbiological processes occurring within the piles.

Nitrogen

Typically, biosolids contain between 1 – 6% total nitrogen (TN) depending on the sludge source and treatment (NZWWA, 2003). After 6 months of composting the sludge/green waste mixtures tested in this study were all at or just below 1 % TN, which is to be expected given the ratios of sludge to GW that was used in the study (1:4). Total N in a mature compost typically ranges from 0.5 – 2.5 % and all 12 sludge composts also fit within this range.

Based on calculations it is apparent that the compost contains more organic N relative to mineralised N (NH_4^+-N and NO_3^--N). While NH_4^+-N and NO_3^--N are immediately available to plants, organic N is only slowly available (when mineralised). All 12 composts would provide adequate nutrition to plants in both the readily available form and in organic N that has potential to be mineralised over time.

Mineralisation is the process whereby organic N is transformed into mineral N available (to microbes and plants) by microbes in soil. Microbes immobilise some of the released N in their biomass, however when the release is greater than their requirements mineral N builds up in soil and is thus available to plants. It has been show that in order for this process to occur the C:N ratio of an organic amendment needs to be below 25:1 (as microbes utilise C and N relative to each other, McLaren and Cameron, 1996). All of the 12 compost windrows in the trial had C:N ratios below 17:1 (ranging from 9-17:1, Table 5.3) and would therefore provide ongoing nutritional value as a soil amendment.

Although NH_4^+-N has reduced from initial levels in many of the windrows it remains high relative to what would be expected from a mature compost (200-500 mg/kg). In all cases NO_3^--N has increased from baseline levels, indicating active nitrification occurring in the compost windrows.

Pathogenic organisms
Data in Table 5.3 indicates that after six months *E. coli* dropped below guideline limits and all 12 windrows could be considered 'Grade A' for microbial contaminants (NZWWA, 2003). In addition, levels of *Campylobacter* and *Salmonella* were below 1 MPN/g for all treatments.

Trace metals
All 12 windrows were below guideline limits for As, Cd, Cr, Cu, Pb, and Ni. However, six windrows exceeded 'grade a' limits for Zn (>300 mg/kg, windrows: 5, 6, 9, 10, 11, and 12). All six of these windrows were digester sludge treatments, indicating that this was the likely source. Interestingly, at the beginning of the trial only two windrows exceeded this limit. It is possible that as the total volume of material reduced throughout the composting process that the Zn was concentrated. All 12 windrows remained below limits for 'Grade b' biosolids.

Total solids
The percent total solids (dry matter) of the composts after six months ranged from 46–64 %, which is consistent with what is to be expected from composted organic products. Composting has been shown to reduce the water content of biosolids which has advantages to transport and handling costs.

Total P
Total phosphorus in the final compost ranged from 0.24 - 1.1 %. Although these values are considered to be high, this compost can be beneficial for plants with a higher P requirement or for soils with low P. The N:P ratio of the composts is similar to that offered by some commercial fertilisers (https://ballance.co.nz/Fertiliser-Products/c/All-Product-Ranges). While the concentration of phosphorus (P) in the compost is high, P is relatively immobile in soils and is not considered a high risk for leaching (NZWWA, 2003). However, P can reach water ways via run-off where it can be potentially harmful (eutrophication). The elevated levels in these composts may indicate it is best used in one off application rates rather than repeat application to avoid the potential build-up of P in soil, and thus potential for leaching into the environment, or limit application to locations where runoff is less likely (not steep topography) with year round plant cover.

Table 5.3.1. Chemical, biochemical and biological analysis of 12 windrows of Palmerston North sewage sludge mixed with green waste after six months.

		Treatment											
Parameter	**Unit**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Nitrate-N	mg/kg	140	4.7	95	160	120	940	160	410	240	190	570	470
Nitrite-N	mg/kg	8.2	3.1	10	99	9.9	40	1.4	23	12	8.7	54	38
pH	pH unit	6.8	7.2	7.5	7.5	7.6	7.1	7.6	7.6	7.4	7.6	7.5	7.8
Ammonium -N	mg/kg	780	1200	860	1500	1600	580	920	1400	180	310	310	1300
Total C	% wt/wt	11	8.6	13	14	14	15	14	14	14	17	16	17
Total N	% wt/wt	0.9	1	1	1.1	1	1	0.9	1.1	1.2	0.6	1	1.2
Total organic C	% wt/wt	9.6	7.8	13	14	14	15	11	12	14	15	14	14
Total oxidised N	mg/kg	150	7.9	110	260	130	980	160	440	260	200	630	500
C:N	% wt/wt	11:1	9:1	13:1	14:1	14:1	15:1	14:1	14:1	14:1	17:1	16:1	17:1
Total P	%	0.26	0.24	1.1	1.1	0.59	0.63	0.52	0.49	0.5	0.44	1.2	1.1
Total solids	%	63.6	61.6	49.2	48.2	50.6	47.3	60.6	47.7	46.6	50.3	47.3	45.9
Voltile solids (OM)	%	30.4	37.4	33.3	34.5	37.1	31.8	30.7	39.2	39.3	38.4	38.9	40.1
As	mg/kg	10	10	14	16	16	16	10	13	9	14	12	9.8
Cd	mg/kg	0.55	0.47	<0.45	<0.45	0.52	0.52	0.41	0.4	0.53	0.51	0.49	0.51
Cr	mg/kg	13	13	14	16	19	21	14	15	14	18	18	17
Cu	mg/kg	56	44	53	50	60	65	38	34	52	52	61	69
Pb	mg/kg	63	52	110	88	110	65	55	34	59	67	58	56
Mg	mg/kg	2400	2400	2300	2600	2700	3000	2400	2500	2500	2800	3100	3200
Ni	mg/kg	7.1	6.5	5.2	5.9	6.5	8.4	6.3	4.9	6.5	7.3	7.8	9.2
Zn	mg/kg	290	260	260	280	350*	340*	240	210	330*	310*	340*	350*
E.coli	MPN/g	<0.028	<0.029	<0.37	<0.37	<0.36	1.6	<0.30	0.94	<0.39	<0.36	<0.38	0.98
Salmonella	MPN/g	<0.024	0.024	<0.031	<0.031	<0.03	<0.032	<0.0099	<0.013	<0.013	<0.012	<0.032	<0.033
Campylobacter	MPN/g	<0.02	<0.02	<0.025	<0.026	<0.025	<0.026	<0.021	<0.026	<0.027	<0.025	<0.026	<0.027

*value exceeds grade "Aa"

Treatments: 1 & 2. Pond sludge + green waste, 3 & 4. Alum sludge + green waste, 5 & 6. Digester sludge + green waste 7 & 8. Pond sludge + Alum sludge + green waste, 9 & 10. Digester sludge + Pond sludge + green waste, 11 & 12. Alum sludge + Digester sludge + green waste

5.4 Composting Efficiency and Quality of End-Product.

Figure 5.4.1 compares analysis of the 12 compost samples against the relevant criteria from NZS4454 (2005) and NZWWA (2003). Based on these criteria 6 of the 12 sludge composts meet all criteria for 'Grade Aa' biosolids as well as those of the composting guidelines. For the 6 windrows that do not meet these criteria Zn is the only parameter that exceeds guideline levels (NZWWA 'Grade a'). The observed concentrations of Zn (310-350 mg/kg) in these composts are well below the limit for 'Grade b' biosolids (1,500 mg/kg) and would therefore be considered safe for use provided the relevant restrictions to use are met. Alternatively, a 'Grade Aa' product could be achieved for all windrows if the composts were mixed prior to use, making them 'unrestricted use biosolids'. Under this category use would be controlled by more permissive rules within the relevant Regional Plans (potentially being a permitted activity). It should be noted that the 6 windrows with elevated Zn are all digester sludge containing composts, suggesting that this is the likely source of Zn contamination. An initial ratio of 1:3 digested biosolids to pond sludge would have reduced Zn to acceptable levels.

The guidelines for composts, mulches and soil conditioners (NZS4454, 2005) state that composting as a means to achieve acceptable stabilisation requires the windrow temperature to be maintained at ≥55 °C for 15 consecutive days with a total of 5 turns and a 30-day maturation phase before use. In our trial the windrows received 5 turns with adequate temperatures (≥55 °C for 15) prior to the final six-month sampling analysis and was indicated to be sufficiently stabilised after this time through levels of *E. coli*, NH_4^+-N and DHA.

All 12 composts would provide adequate nutrition to plants in the form of P, K and N in both the readily available form of N and in organic N that has the potential to be mineralised over time (providing ongoing nutritional value). This combined with the low C:N ratio indicate that the composts would provide adequate nutrition to plants if used as a soil amendment.

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Figure 5.4.1. Assessment of 12 sludge composts after six months against criteria for New Zealand Standards for composts and Mulches (NZS 4454, 2004) and the New Zealand Biosolids Guidelines (NZWWA, 2003).

		Limit		Windrow met criteria after 6 months											
Parameter	**Unit**	**NZS4454**	**Biosolids guidelines 'Grade Aa'**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Biochemical															
pH	pH units	5.0 - 8.5	-	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Total Nitrogen	% DM	> 0.6	-	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Organic matter content	% DM	≥ 25	-	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Pathogens															
E. coli	MPN/g	< 100	< 100	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Campylobacter	MPN/25g	n/a	< 1	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Salmonella	MPN/25g	n/a	< 1	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Trace Metals															
Cadmium (Cd)	mg/kg	3	1	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Chromium (Cr)	mg/kg	600	600	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Arsenic (As)	mg/kg	20	20	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Lead (Pb)	mg/kg	250	300	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Nickel (Ni)	mg/kg	60	60	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Mercury (Hg)	mg/kg	2	1	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Zinc (Zn)	mg/kg	600	300	✓	✓	✓	✓	✗	✗	✓	✓	✗	✗	✗	✗
Copper (cu)	mg/kg	300	100	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Temperature	°C	> 55°C for 15d	-	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Meets criteria for use for NZS4454				✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Meets criteria for Grade Aa Biosolids				✓	✓	✓	✓	✗	✗	✓	✓	✗	✗	✗	✗

✓	Criteria met
✗	Criteria not met

Treatments: 1 & 2. Pond sludge + green waste, 3 & 4. Alum sludge + green waste, 5 & 6. Digester sludge + green waste 7 & 8. Pond sludge + Alum sludge + green waste, 9 & 10. Digester sludge + Pond sludge + green waste, 11 & 12. Alum sludge + Digester sludge + green waste

5.5 Limitations of Trial

Due to time and financial limitations for this project organic contaminants present in the composts were not tested, this is considered to be useful data for future work and would add significantly to the bigger picture of biosolids use. In addition, the testing of plant propagules was not carried out, a compost must have nil growth of weeds after 21 days to be considered a compost.

The initial construction of windrows was not consistent across all treatments due to sourcing and equipment issues. Therefore, composting occurred over different seasonal fluctuations which would potentially alter the speed with which the material degraded and the microbiological processes occurring within the piles, making comparisons between treatments problematic.

6 RANGITĀNE O MANAWATŪ CULTURAL IMPACT ASSESSMENT

6.1 Introduction

Crown approach to wastewater management has been a long-standing issue for Rangitāne o Mananwatū (RoM), and little work has been done until recently to understand the basis of the concerns or incorporate RoM values into wastewater management. Rangitāne o Manawatū are a critical stakeholder in waste management through their position as holding mana whenua in the Manawatū region. The opportunity to participate in the establishment of a biosolids composting trial at PNCC, and feed into the Collective Biosolids Strategy, was an important step for RoM rangatiratanga and tiakitanga responsibilities.

Before any cultural monitoring program can be undertaken a researcher must have a holistic understanding of the values that underpin the research kaupapa. It is the cultural values that a cultural monitoring program is based upon, they guide both what will be measured when planning cultural monitoring and set the researcher up to be able to draw meaningful conclusions from the results. Understanding Rangitāne o Manawatū values around waste, and specifically biosolids is therefore an important step for this project.

6.2 Scope

Assess the cultural effects of Biosolids Composting at Awapuni Resource Recovery Centre, and high -level considerations for Beneficial Reuse within the Rangitāne o Manawatū area of interest through the production of a cultural impact assessment (CIA).

6.3 Methods

A CIA was generated by Te Ao Turoa Environmental Centre (TATEC), the health, social service and environmental arm of Tanenuiarangi Manawatū Incorporated (TMI, the Iwi Authority for Rangitāne o Manawatū). The RoM cultural values assessment was led by Siobhan Karaitiana.

Initial stages involved the development of an information package outlining terminology and key details of the trial to allow iwi members to participate effectively. Following this a range of iwi members were interviewed including:

- Four rangatahi (youth);
- Two university students;
- Five pakeke (adults); and
- Two kaumatua (elder).

Participants were interviewed and asked to score a range of kaupapa/topics according to how they felt (1-5). Qualitative data was recorded in an excel spreadsheet and basic statistics calculated to gain an overall score for each question. Nineteen questions were presented in total covering topics from participants existing knowledge on biosolids to discussing potential options for biosolids use (see Appendix B).

6.4 Results and conclusions

Participants had a wide range of prior knowledge about biosolids and biosolids management ranging from little to in depth understanding. Biosolids management was important to participants, but even more important to their hapū and iwi identity. Participants were slightly more comfortable interacting physically and spiritually with biosolids application sites but less so harvesting kai. An even split of participants identified that they would be comfortable undertaking limited recreation such as walking, hiking or passing through a site containing biosolids whilst others said they would not like to interact with biosolids at all.

All participants agreed that the length of time since application was important, and an ecologically/ culturally healthy area would heal the tapu of biosolids faster than leaving the area in a degraded state. All participants identified that restoring biodiversity and undertaking karakia in parallel to discharging biosolids would make them feel more comfortable interacting with a site because they could see and feel the environment healing the waste.

Interestingly, whilst composting was viewed positively, with 'scientific safety' of the product allowing participants to discuss the finer details of tikanga with comfort, it did not significantly alter participants views on acceptable use options.

"Composting will make it (the biosolids) environmentally and culturally healthier, but it needs to be used in appropriate places" (Karaitiana, 2019).

Some primary outcomes of the CIA were:

- It's was unanimously agreed that full beneficial use of biosolids needed to occur;
- Landfilling of biosolids was strongly rejected based on both environmental and cultural concerns;
- Non-food producing locations such as forestry or biodiversity regeneration were viewed most favourably;
- Use of biosolids to condition soil during restoration projects was strongly supported;
- It is important that biosolids are not applied around waterways and wahi tapu. The presence of a buffer may alleviate this concern; and
- There is evidence that plants transfer the tapu around biosolids into noa
  - However, participants were still uncomfortable about the concept of animals gazing on land containing biosolids, or 'cut and carry' where produce is grown and fed to animals that will then be consumed by people;
- It is suggested that the length of time is an important factor for lifting tapu, fully transitioning the tapu of biosolids into noa can take up to a decade; and
- Whilst composting was viewed positively, it did not significantly alter the participants views on acceptable use options.

The full Te Ao Turoa Environmental Centre Cultural Impact Assessment can be found in Appendix B.

7 CONCLUSIONS

This trial aimed to investigate the practical and/or technical viability of multiple source sludge composting by way of a large-scale trial.

The composting process stabilised microbial contaminants and effectively diluted chemical contaminants to produce a product that met guidelines for composts in NZ (NZS4454, 2005) and 'Grade Aa' and/or 'Grade Ab' biosolids (NZWWA, 2003). This was evident in all three contrasting sludge products used for this trial suggesting that, excluding high levels of chemical contaminants, the sludge used in the initial feedstock had little effect on the quality of the final product.

Trace metals are not removed by composting and in the case of the digester sludge compost windrows in this trial dilution factors for Zn were not sufficient for reducing levels to below 'Grade a' limits. This indicates that whilst initial dilution of material may reduce trace metals to below guideline levels, the reduction in volume of the pile through biological degradation will serve to concentrate these contaminants in the final compost. It is suggested that this should be taken into account when diluting heavy metal containing biosolids, in the case of our trial a ratio of 1:3 digested biosolids to pond sludge would have reduced Zn to acceptable levels.

Composting reduced the moisture content of the initial product which is to be expected from composted organic products. Composting has been shown to reduce the water content of biosolids, reduced water content can make transport of the material easier due to improved handling. In addition, results from analysis of *E. coli*, NH_4^+-N and DHA indicated that the sludge compost was sufficiently stabilised after six months, with levels of available and organic N that would provide immediate and long-term nutritional value to soils and plant.

Based on the results of this trial it is suggested that commercial composting, under optimal conditions and following recommended procedures, is a viable means of producing a material suitable for a wide range of end uses which might otherwise not be available to un-composted WWTP sludge.

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9 APPENDICES

Appendix A: Windrow photos from monthly sampling of compost
Appendix B: Te Ao Turoa Environmental Centre Cultural Impact Assessment

APPENDIX A

Windrow photos from monthly sampling of compost

Figure 4.8. Windrow 3, PNCC alum sludge + green waste. Photos taken on on 5th August after 4 months of composting.

Figure 4.9. Windrow 3, PNCC alum sludge + green waste rep a. Photos taken on 14th October after 8 months of composting.

Figure 4.10. Windrow 10, PNCC digester sludge + oxidation pond sludge + green waste. Photos taken on 5th August after 4 months of composting.

Figure 4.11. Windrow 10, PNCC digester sludge + oxidation pond sludge + green waste. Photos taken on 14th October after 6 months of composting.

Figure 4.12. Eise Venter on site at PNCC prior to the June compost sampling

APPENDIX B

Te Ao Turoa Environmental Centre Cultural Impact Assessment.

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Te Ao Turoa Environmental Centre

Cultural Impact Assessment

To

Lowe Environmental Impact

Biosolids Composting Trail

Nā Siobhan Karaitiana
Environmental Planner
Te Ao Turoa Environmental Centre
November 14, 2019

Ka kahutia i te korowai, Te Rangimarie, Te Aroha, Te Whakaiti, Ka Whakapuawai he iwi humaarie
Spread the cloak of Peace and Love, so shall blossom the people of humility

Mihi

Te Mauri o Rangitāne o Manawatū

E inoi nei ki ngā whakatipuranga a Tanenuiarangi

Kia tū whakapakari me matekitetia mō ngā rā ka

Hekemai mō te oranga tinana, oranga wairua

Teitei Kahurangi.

Whakatuwheratia o hā, me tō hinengaro toro atu

O ringa kia awhitia rātau mā i urumai i waenganui i a mātou,

Manaakitia te katoa ahakoa tō rātou karangatanga maha

Me kaha te tiaki kia pai ai ngā wawata,

Ngā moemoea.

Kia ū ki ngā whakaarotanga

A ō mātou Matua Tupuna.

Kia noho tonu a rātou wairua ki runga ki tēnā

Ki tēnā mō ake tōnu atu.

Ma Ihoa tō tātou piringa me te kaiarahi i runga i to haerenga.

Contents

1.0 Background

Lowe Environmental Impact (LEI), Massey University and The Institute of Environmental Science and Research Ltd (ESR) are working in partnership with ten lower North Island Councils to develop a biosolids strategy that includes the potential for a collective approach to sludge management and beneficial end-use. Through earlier phases of the project it was estimated that there are around 80,000 tonnes of sludge produced from oxidation ponds every 30-50 years in the lower North Island, excluding additional sludge from five high rate treatment plants. Currently, most of the sludge removed from treatment plants is disposed of in local landfills.

Rangitāne o Manawatū are a critical stakeholder in waste management through their position as the mana whenua in the Manawatū region. Mana whenua have an intrinsic responsibility to protect, restore and safeguard the world around them for future generations. Furthermore, integrating indigenous worldviews into local decision making is critical in reducing human impacts on the environment, protecting historic heritage, fulfilling Crown obligations as Treaty partners, and maintaining the wairua and mauri of Te Ao Māori.

Rangitāne o Manawatū have never had the opportunity to address the cultural impacts associated with transport and landfilling of biosolids. It is a permitted activity and local landfill receiving environments are located outside of Rangitāne o Manawatū area of interest (Figure 1). Identification of alternative solutions to landfilling of biosolids however will likely require consent and consultation with Rangitāne to identify potential effects that the discharges may have on the iwi and their values. Palmerston North City Council (PNCC) owns and operates a biosolids and wider composting site located in Awapuni. This composting site has hosted the Biosolids Composting Trial. The trial is assessing health and safety of the compost product against New Zealand Biosolids Guidelines, and time taken to reach the safety threshold. The biosolids used in this experiment have come from within the Rangitāne o Manawatū rohe; the disestablished Bunnythorpe wastewater treatment plant and Palmerston North wastewater treatment plant.

2.0 Purpose of the Report

This Cultural Impact Assessment (CIA) describes and analyses a range of Rangitāne o Manawatū iwi members perceptions relating to appropriate end use of the composted biosolids and rehabilitation of old pond sites; it identifies values, interests and associations with the Awapuni area where biosolids extraction and composting has taken place. A CIA is usually commissioned throughout a resource consent process and is regarded as technical evidence, however, in this instance it has been commissioned to inform the lower North Island Biosolids Strategy. One of the units of Best Care (Whakapai Hauora) Charitable Trust, the health, social service and environmental arm of Tanenuiarangi Manawatū Incorporated, the Iwi Authority for Rangitāne o Manawatū is Te Ao Turoa Environmental Centre (TATEC). TATEC have generated this CIA.

As Treaty Partners and Kaitiaki, Rangitāne o Manawatū are interested in the outcomes of Lower Manawatū Biosoilids Composting Strategy and how they will affect Rangitāne o Manawatū values and wāhi tapu in the Manawatū.

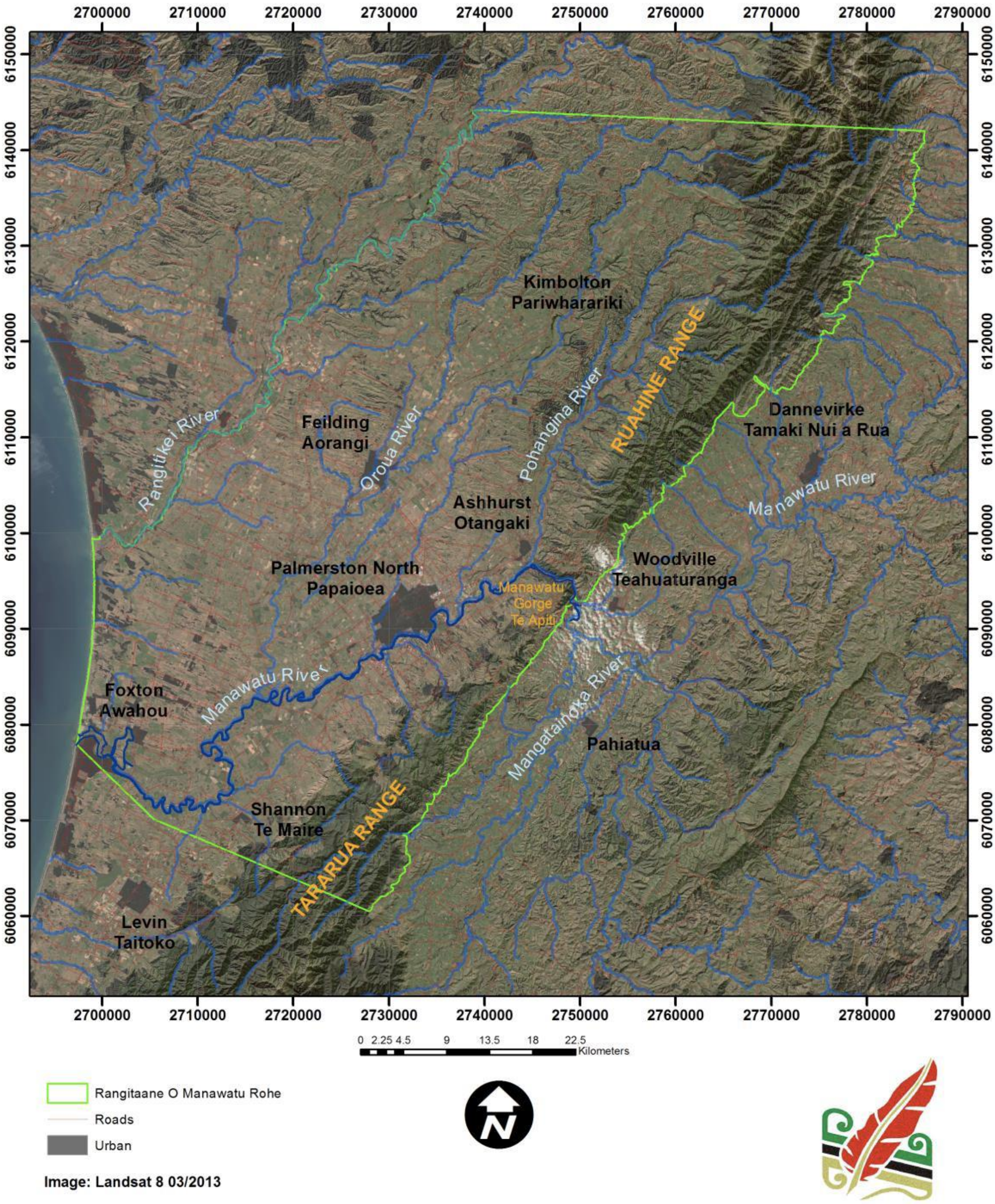

Figure 1: Rangitāne o Manawatū area of interest.

3.0 Te Whanonga Pono a te Taiao ō Rangitāne o Manawatū

Te Whanonga Pono a te Taiao ō Rangitāne o Manawatū are key values held by Rangitāne o Manawatū that guide Te Ao Turoa Environmental Centre (TATEC) in conducting CIA's. It is important the reader is familiar with these concepts early in order to understand discussion about cultural impacts related to the Biosolids Composting Trial and wider strategy.

<u>Te Ao Māori</u>

A Māori worldview is based on the holistic principle that all elements are interrelated. Every part of the environment is understood to have a common genealogy, descending from a common ancestor. The principle ancestors being Io matua te kore (Io the Parentless), Ranginui and Papatūānuku (Sky Father and Earth Mother), and their atua tamariki (142 known demigods/goddesses). This genealogy places Māori people as descendants of the land and the environment they inhabit. It reinforces cultural identity and a deep connection to the land.

<u>Tino Rangatiratanga</u>

Tino Rangatiratanga is absolute sovereignty and self-determination, having ownership, rights, control over, and possession of Māori lands, waters, and taonga. Article Two of the Treaty guarantees Māori Tino Rangatiratanga, which is fundamental to Māori wellbeing.

<u>Mana Whenua</u>

The concept of mana whenua is a key to understanding the environmental management philosophies of Māori. Mana whenua as defined by the Resource Management Act (1991) is the customary authority exercised by an iwi to control and manage an area or resource in relation to prescribed customary and cultural practices. The authority is obtained through the relationship of the people and their ancestral connection to the land.

<u>Tangata Tiaki</u>

A Tangata Tiaki is a guardian or caretaker. It is the processes and practices people of Rangitāne o Manawatū take in protecting the environment for future generations.

Rangitāne-nui-a-rawa

Is the undertaking of Tiakitanga with a Rangitāne philosophical approach. Rangitāne o Manawatū responsibilities require tangata whenua to guard over all aspects of the natural world, which were created by the Atua children of Ranginui and Papatūānuku.

Wairuatanga

Wairuatanga is a Māori framework that acknowledges the coexistence of the physical and spiritual dimensions. Wairuatanga is an energy force that connects all aspects of life. Rangitāne o Manawatū continue to support the essence of wairuatanga through karakia, rituals and cultural practices.

Tikanga

Tikanga defines the appropriate protocol for undertaking an activity, it sets objectives and processes that individuals and organisations must achieve when undertaking an action.

Mauri

Mauri is the life force of all living and non-living things. It is the essential quality and vitality of a being or entity. Mauri is used in assessing ecosystems subject to human change, any damage, alteration or contamination to the environment will affect the mauri that it possesses.

Taonga

Taonga are tangible and intangible components of Te Ao Māori. Taonga is anything that is of value or treasured including places, people, language, objects, flora and fauna.

Mātauranga Māori

Mātauranga Māori is the knowledge, comprehension, or understanding of everything visible and invisible existing in the universe. Pūrākau and Maramataka, forms of mātauranga Māori, comprise knowledge generated using methods and techniques developed independently from other knowledge systems.

Taonga tuku iho

Taonga tuku iho is the intergenerational transmission of Mātairanga Māori. Taonga that are handed down from generation to generation.

Ritenga

Ritenga are everyday rituals and practices that sustain the well-being of people, communities and natural resources. Everything is balanced between regulated and de-regulated states; wāhi tapu is to be restricted or sacred with specific associated tikanga; rahui is to temporarily restrict; and noa is relaxed or unrestricted. Appropriate protocols such as karakia (prayer) can shift the regulation of states from being tapu to noa in appropriate situations.

4.0 Perceptions Study

4.1 Methodology

Site visits were undertaken at Awapuni Resource Recovery Centre with representatives from Rangitāne o Manawatū, LEI and PNCC to discuss the Biosolids Composting Trial. TATEC was invited to put forward a proposal to assess the cultural effects of Biosolids Composting at Awapuni Resource Recovery Centre, and high -level considerations for Beneficial Reuse within the Rangitāne o Manawatū area of interest. The scope was expanded to consider the rehabilitation of old pond sites. A final iteration of the framework can be found in Table 1, with description of the methodology in Appendix A.

An information package was developed (Appendix B) so that iwi members contributing to the assessment understood all terminology and key details necessary to be able to participate effectively. A range of iwi members were interviewed, including four rangatahi, two university students, five pakeke, and two kaumātua. The thirteen participants kōrero was recorded for use in the CIA (Figure 3). Participants were asked to give a score between 1-5 dependant on how they felt about each kaupapa/topic (Figure 2). Three pakeke and the four rangatahi were interviewed in a group therefore a single score was given according to agreement from the whole group. Notes taken during the assessments were verified against an electronic recording, any points lacking clarity were reviewed by participants to ensure the kōrero was interpreted correctly by the author. Quantitative data was recorded in an excel spread sheet and basic statistics were calculated to express an overall score for each question.

Table 1: Biosolids Composting Perceptions Framework– Ecological, Cultural and Social indicators

Questions					
1. Have you heard about biosolids before today? If yes from which sources?	1~ No I haven't herd of biosolids before today.	2~	3~ Understanding of biosolids and environmental management issues.	4~	5~ Very good understanding and biosolids environmental management issues.
2. Are you concerned about how biosolids are managed?	1~ No concern for what happens to biosolids.	2~	3~ I am concerned about the way biosolids are being managed.	4~	5~ I am very concerned about management of biosolids.
3. How important/significant do you think biosolids management is to your whanau/hapū?	1~ Not significant	2~ Somewhat significant	3~ Significant	4~ Quite significant	5~Extremely significant, hapū should be involved with management of local sites.
4. How important/significant do you think biosolids management is to your Iwi?	1~ Not significant	2~ Somewhat significant	3~ Significant	4 ~ Quite significant	5~ Extremely significant. Tikanga should be overseen by Iwi leaders.
5. Would you visit a site containing composted biosolids for recreation (hiking, swimming, picnic) or cultural activities (wānanga or healing)?	1 ~ No I wouldn't visit for anything.	2 ~	3 ~ I would visit for limited recreation and cultural activities eg while hiking.	4 ~	5 ~ Yes I would visit a site with my tamariki/moko/teina for a swim and a picnic.
6. Would the length of time since application of composted biosolids affect whether you feel comfortable recreating at a site or undertaking cultural activities?	1~ No amount of time would make me feel more comfortable.	2 ~	The length of time since the last biosolids application would increase the likelihood I would feel comfortable.	4 ~	5~ Yes, the length of time since the last biosolids application would increase the mauri of the site to where I would feel comfortable.
7. Would you visit a site containing composted biosolids and collect kai or rongoa?	1 ~ No I wouldn't harvest there.	2 ~	3 ~ I would collect limited resources eg leaves or berries on a tall tree.	4 ~	5 ~ Yes I would visit a site with my tamariki/moko/teina for harvesting.
8. Would the length of time since application of composted biosolids affect whether you feel comfortable harvesting at a site?	1~ No amount of time would make me feel more comfortable.	2~	3~ The length of time since the last biosolids application would increase the likelihood I would harvest some resources.	4~	5~ Yes, the length of time since the last biosolids application would give me the ability to freely harvest resources.
9. What should be done with composted biosolids?	1 ~ Status quo	2 ~	3 ~	4 ~	5 ~ Full beneficial reuse.
10. Name any acceptable reuse options:					
11. Name any unacceptable options for reuse:					

12. Would you visit a site containing a decommissioned pond for recreation or cultural activities?	1 ~ No I wouldn't visit for any type of activity.	2 ~	3 ~ I would visit for limited recreation.	4 ~	5 ~ Yes I would visit a site with my tamariki/moko/teina.
13. Would the length of time since decommission affect whether you feel comfortable recreating at a site or undertaking cultural activities?	1~ No amount of time would make me feel more comfortable.	2 ~	The length of time since the pond was decommissioned would increase the likelihood I would feel comfortable.	4 ~	5~ Yes, the length of time since the pond was decommissioned would increase the mauri of the site and I would feel comfortable.
14. Would you visit a site containing a decommissioned pond and collect kai or rongoa?	1 ~ No I wouldn't harvest there.	2 ~	3 ~ I would collect limited resources eg leaves or berries on a tall tree.	4 ~	5 ~ Yes I would visit a site with my tamariki/moko/teina for harvesting.
15. Would the length of time since decommission affect whether you feel comfortable harvesting at a site?	1~ No amount of time would make me feel more comfortable.	2~	3~ The length of time since the pond was decommissioned would increase the likelihood I would harvest some resources.	4~	5~ Yes, the length of time since the pond was decommissioned would give me the ability to freely harvest resources.
16. What should be done with a decommissioned pond?	1 ~ Nothing should be done.	2 ~	3 ~	4 ~	5 ~ It needs a full environmental and cultural restoration.
17. What should be done if a sewage pond was located on a wāhi tapū?	1 ~ Nothing should be done.	2 ~	3 ~	4 ~	5 ~ It needs a full environmental and cultural restoration.
18. Name any acceptable use options for old sewage pond sites:					
19. Name any unacceptable options for old sewage pond sites					

4.2 Results

Participants had a wide range of prior knowledge about biosolids and biosolids management ranging from little to in depth understanding. Biosolids management was important to participants, but even more important to their hapū and iwi identity. Participants perceptions and considerations were similar for both biosolids application sites and rehabilitated of pond sites. Participants were slightly more comfortable interacting physically and spiritually with the sites over harvesting kai in both scenarios. There was strong support for beneficial reuse for biosolids and full environmental and cultural restoration of pond sites, and an absolute resolve for setback, environmental and cultural restoration for wāhi tapu.

4.3 Quantitative Results

Table 2. Summarised scores of Rangitāne o Manawatū perceptions towards biosolids composting and wastewater treatment pond rehabilitation.

Question Number	Mean	Min	Median	Max
1	2.7	1	2	5
2	4.0	3	4	5
3	5.0	5	5	5
4	5.0	5	5	5
5	2.5	1	2	4
6	4.7	4	5	5
7	2.2	1	2	3
8	4.7	4	5	5
9	4.7	3	5	5
10	-	-	-	-
11	-	-	-	-
12	2.8	1	3	5
13	4.7	4	5	5
14	2.0	1	2	3
15	4.7	4	5	5
16	4.7	3	5	5
17	5	5	5	5
18	-	-	-	-
19	-	-	-	-

4.4 Qualitative Results

Table 3: Summarised Responses of Rangitāne o Manawatū perceptions towards biosolids composting and wastewater treatment pond rehabilitation.

Question	Summary
1	Participants had little to no understanding of the term biosolids. However, were very aware of other high-level issues around wastewater management, especially pollution of freshwater and climate change. This understanding came from whānau discussions, lack of access to unsafe sites that used to be safe, being exposed to an increasing number of adverse weather events, social media and news outlets.
2	All participants were moderately to very concerned about how biosolids management affected them personally. There was a strong desire for knowledge and education about the topic to increase.
3	All participants identified a strong need for hapū representatives to be engaged in local biosolids management. “They are the caretakers of the land and waterways for their children”. Tikanga: Hapū have specific wāhi tapu that should be considered and protected.
4	All participants identified a strong need for Iwi representatives to be engaged in biosolids management, especially strategically across the rohe (area of interest). “Iwi have the responsibility to protect the river (Manawatū River), wāhi tapu and Te Ao Māori, they are our taonga for future generations”.
5	An even split of participants identified that they would be comfortable undertaking limited recreation such as walking, hiking or passing through a site containing biosolids. Others said they would not like to interact with biosolids at all. “If I knew that it (biosolids) was surrounding me I wouldn’t feel right, I would move on quickly”, “The tapu side of me is saying no dont go there, no kids in there playing”.

	Tikanga: Wharepaku traditionally well away from whare; Historically whānau would use the slope of the whenua to filter wastewaters through vegetation and wetlands, these areas were not used for any other purpose and kept separate.
6	All participants identified that time since biosolids application would make them feel more comfortable being around the site for recreation (such as walking, picnics, swimming) and cultural activities (such as wānanga, mahi toi). Tikanga: Comfort levels increased depending on the perceived ecological/cultural health of the area being presence of indigenous species.
7	Participants were slightly less comfortable taking kai (food) and rongoa (medicine) from an area containing biosolids. However, some participants were comfortable with the idea of limited harvest, where the resource had not been in direct contact with the biosolids eg leaves or berries from a tree. Others were very uncomfortable with the idea. "It would be like taking kai from the urupa".
8	All participants agreed that time since application of biosolids would increase their comfort levels for harvesting kai and rongoa. However, a longer timeframe was identified, multiple decades instead of a single decade or less for recreation and cultural activities. Tikanga: An ecologically/ culturally healthy area would heal the tapu of biosolids faster than leaving the area in a degraded state.
9	Its was unanimously agreed that full beneficial re-use of biosolids needed to occur. "Composting will make it (the biosolids) environmentally and culturally healthier, but it needs to be used in appropriate places".
10	In materials, forestry and for restoration of biodiversity. Tikanga: "Our responsibility as kaitikai is to leave it (any place) in a better state than what we found it in". A single or few large sites were prefered rather than many small sites.
11	Direct contact with food or medicine, on wāhi tapu, landfilling, waterways need a setback, children's playgrounds, vegetable gardens or gardens where the public interact closely.
12	As with question 5. Limited recreation was identified by some participants as acceptable, while others were uncomfortable being in an old pond site for recreation or cultural activities.
13	All participants agreed that time would increase their comfort to be in a rehabilitated pond site. Tikanga: Don't swim or collect kai from old pond sites.
14	Unanimously "no"
15	Most participants said time would increase their comfort.
16	All participants identified that a full cultural and environmental restoration should be undertaken in old dis-used or inappropriately placed pond sites. "Trust Papatūānuku, that she can turn the bad back into good, and ensure health going forward for area".
17	All participants identified the need for full cultural and environmental restoration for wāhi tapu used as wastewater treatment pond sites. "A comprehensive team of cultural and ecological experts would be required to deal with issues on wāhi tapu". Most participants feel that pond sites on or adjacent to wāhi tapu should be restored immediately instead of waiting until the end of the ponds life. "Māori would feel disrespected if biosolids or wastewater treatment pond sites were impacting the mauri of their wāhi tapu, especially urupā".
18	Cultural and environmental restoration for biodiversity. "The mauri of pond sites must be restored before the site can be used". "It shouldn't just be left and abandoned".
19	Grazing, growing food, for urupā.

4.5 Discussion

Bio-indicators are a common way Māori assess the health of the world around them, this concept has strong support in this investigation. All participants identified that restoring biodiversity and undertaking karakia in parallel to discharging biosolids and during pond rehabilitation would make them feel more comfortable interacting with a site because they could see and feel the environment healing the waste. They also identified that the presence of biodiversity and occurrence of karakia would speed up healing time so that the land could be used again in the future. There was no noticeable difference between participants views on biosolids discharge and pond rehabilitation management. This strong theme gives guidance on what Rangitāne o Manawatū see as appropriate beneficial end uses. Conditioning soil during restoration projects was strongly supported, however it was important that biosolids were not applied immediately around waterways and wahi tapu. The presence of a buffer could likely alleviate this concern, the buffer width dependant on how important and well spatially defined the stream and wāhi tapu. Growth of plants for materials was also strongly supported by all participants, building evidence that plants transfer the tapu around biosolids into noa.

In contrast all except two participants felt uncomfortable about the concept of animals gazing on land containing biosolids, or 'cut and carry' where produce is grown and fed to animals that will then be consumed by people. Following the premise that plants can heal tapu then it is surprising to find that this does not alleviate Rangitāne concern around grazing animals on land or feed conditioned with biosolids. It is likely that time is the significant factor dividing the evidence. Application on restoration sites and forestry for materials implies that tree growth and healing of biosolids will occur over decades. It is through this lengthy process that tapu can be lifted whereas biosolids application to land for cropping allows only one or two seasons of healing time. Based on participants indication of 'time required before they would feel comfortable interacting with biosolids', one or two seasons would be insufficient for tapu to be lifted. This raises an interesting piece of counter evidence to the widely held view that iwi overwhelmingly support wastewater discharge to land so that the Papatūānuku/ Earth Mother can filter, recycle and reuse nutrients contained in the product. Often land identified for wastewater irrigation is agricultural. While this study did not directly assess this, it could be argued that biosolids and wastewater have similar associated tikanga. Importantly identified in this study is a piece of traditional tikanga; wetlands and natural land passage was a traditional way for managing human waste discharges.

Historically Māori did not interact with human waste products in day to day life. Wharepaku/toilet areas were located well away from food gathering, storage and cooking areas, sleeping and working quarters. The tikanga around division of activities has revealed itself in this study where Rangitāne are generally uncomfortable with biosolids products being applied in areas with considerable public interaction such as children's playgrounds and town gardens, and in areas associated with food production. Urupā are particularly sensitive and should not be considered as receiving environments for biosolids. Landfilling of biosolids was strongly rejected based on both environmental and cultural concerns, and support was unanimous for full beneficial reuse of the biosolids. The quantum of biosolids produced in the lower North Island is significant. Rangitāne o Manawatū iwi members were committed to fully realising their duty as Tangata Tiaki in supporting local Councils to find the best practicable beneficial reuse option that acknowledges and negotiates both western science and traditional tikanga.

5.0 Lower North Islands Biosolids Strategy Assessment

The three broad biosolids strategies (the Strategies) were not accessible during design and implementation of the Perceptions Study (the Study). The recommendations made in this section take learnings from the Study and apply them to assessing The Strategies.

5.1 Strategy 3

Strategy 3 (Table 4) is the least desirable strategy to Rangitāne o Manawatū. The status quo discharges biosolids is in way that is both culturally and environmentally damaging.

Cultural Issues

- No effort is made to lift the tapu from biosolids before discharging them to Papatūānuku. The Cultural Impact of poor biosolids management on Rangitāne o Manawatū is significant according to Section One (questions 1-4) of the perceptions study. Values such as Rangitāne o Manawatū ability to fulfil Tangata Tiaki duties, apply their traditional Mātauranga, protect the Wairua of the iwi and Te Ao Māori are currently being impacted in a way that is considerably more than minor.

Environmental Issues and Contemporary Mātauranga

- Mātauranga Māori is not static. It develops and grows over time in response to environmental change. Rangitāne o Manawatū broadly understand the historical and contemporary issues associated with landfills; toxic leachates and greenhouse gas discharges continue to impact on natural processes in Te Ao Māori. A conservative estimate of 80 000 tonnes of biosolids has gone to landfill in the past 50 years. Collective Strategies 1 and 2 have the potential to develop and support mātauranga in a positive way, moving beyond the negative perceptions around current and past biosolids management practices.

5.2 Strategy 1 and 2

Strategy 1 identifies the use of one or more main treatment facilities. Rangitāne o Manawatū assessment addresses the effects of this activity at the Palmerston North City Council composting site, Awapuni.

Cultural Issues

- The Awapuni composting site is located immediately adjacent to the Manawatū River and significant wāhi tapu; Maraea Tarata and Māraratapa, fortified Pā (Figure 2).
- Runoff from the composting operations enters the pond south west of the site. The pond is exchanging water with the Manawatū River and on the margin of the pond was Māraratapa Pā.
- The discharge pond does not recognise an appropriately sized setback from biosolids runoff, the pond also does not support bio-indicators of a healthy environment.

Strategy 2 identifies a common end use for biosolids discharge. A broad set of principals are given for consideration under this option.

Cultural Issues

- Set back is allowed for wāhi tapu and waterways.
- Urupā are not considered for receiving environments of biosolids.
- Biodiversity can be monitored by Rangitāne o Manawatū using a 'Rangitānenuiarawa Cultural Health Framework', with allowance for activities that will increase biodiversity.
- A single or few larger sites are preferred over many small sites. Tikanga can be more adequately managed in fewer locations.

It was clear from the Perceptions Study that Rangitāne o Manawatū iwi members supported Strategy 1 and 2 significantly more than Strategy 3. Transfer of biosolids between rohe to a centralised composting site or to a common discharge site was not assessed in the Perceptions Study, however TATEC support this approach above transfer of biosolids between rohe for landfilling. TATEC would be happy to reaffirm this position with Rangitāne o Manawatū iwi members.

Figure 2: Wahi tapu affected by the Awapuni Composting Site.

Table 4: Proposed Broad Lower North Islands Biosolids Strategies

Strategy 1	The principle basis of Strategy 1 is the communal use of existing infrastructure at an identified high rate WWTP for the dewatering and treatment/stabilisation of sludge from smaller community WWTPs. It was determined that by utilising one (or more) main treatment facility the chance of producing a high-quality end-product with greater potential for re-use is more likely. In this scenario a 'high quality end-product' is defined as meeting Grade A in the current NZ Guidelines for the Safe Application of Biosolids to Land (NZWWA, 2003).
Strategy 2	Strategy 2 (Figure 3.3) focuses on independent treatment but with a common end-use; in this case a communal land discharge site is suggested. The main driver for Strategy 2 is a common, beneficial end-use with less associated costs than landfill or independent discharge. Geobags have been highlighted as a valuable de-watering and stabilising technique (Stage 1 T2b, Site and field investigations) and have been recommended here.
Strategy 3	Strategy 3 (Figure 3.4) represents the 'status quo' in terms of discharge practice in many cases. Including the use of a common contractor and utilising one preferred discharge site (i.e. Bonny Glen or Levin landfill) may reduce associated costs through a reduction in consenting requirements and reduced landfill fees.

6.0 Conclusions

6.1 Perceptions Study

- Rangitāne o Manawatū are concerned about the status quo of biosolids management and consider that it is important for hapū and iwi to have a strong role in decision making around biosolids management.
- Supporting biodiversity and undertaking karakia in parallel to discharging biosolids and during pond rehabilitation will speed up healing time so that the land could be used again for a range of purposes in the future.
- Iwi members are generally concerned about the integration of biosolids into the food chain.
- Fully transitioning the tapu of biosolids into noa can take up to a decade.

6.2 Lower North Island Biosolids Strategy

- Strategy 3: is the least desirable strategy to Rangitāne o Manawatū, it has the highest level of cultural impacts that are not able to be mitigated or offset.
- Strategy 1: A centralised composting point is supported by Rangitāne o Manawatū, however the current location of the Awapuni composting site leachate pond is located inappropriately and poorly managed for Cultural Health.
- Strategy 2: A centralised discharge point is supported by Rangitāne o Manawatū, with appropriate tikanga considered and provided for.

7.0 Disclaimer

This report is the intellectual property of TATEC. LEI can use this report to inform the Lower North Island Biosolids Composting Strategy and shall consult with TATEC if this report is going to be used for other purposes.

This CIA was undertaken on behalf of Rangitāne o Manawatū. Rangitāne o Manawatū encourage parties undertaking biosolids management to consult directly with all iwi that have interests in the affected area.

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9.0 Appendix A: Perceptions Study Cultural Health Index Explanation

Component One- Questions 1-4

This component of the Framework explores the significance of the kaupapa (biosolids management) to Rangitāne o Manawatū and distinguishes between personal, hapū and Iwi values. The first and second questions “Have you heard about biosolids before today?” and “Are you concerned about how biosolids are managed” considers personal knowledge and values. Questions three and four “How important/significant do you think biosolids management is to your whanau/hapū or Iwi” considers the different levels of identity that exist for Rangitāne.

Component Two and Three- Questions 5-19

The second and third component of the Framework looks at the Cultural Practices and Values vital to the physical, spiritual, social and emotional wellbeing of Rangitāne o Manawatū, which are provided for by Tāne, Rongomatāne, Haumietiketike and Tūmatauenga. This component explores tikanga around the appropriateness of site use and ability for cultural activities to take place on sites containing composted biosolids and decommissioned ponds, and whether time may be able to restore Noa. The following three broad categories of activities are considered.

A. Wellbeing
B. Harvesting kai and rongoa
C. Reuse options

10.0 Appendix B: Biosolids Background Information- Perceptions Study

Biosolids are a technical word for the sludge that builds up on the bottom of sewage treatment ponds. They are the solid component of human wastewaters.

Picture 1: Wastewater treatment pond containing biosolids

Sewage treatment ponds build up with biosolids over time. The biosolids must be extracted from the pond for it to continue to treat sewage waters effectively. Biosolids are often sent to landfill for disposal. Another option is to compost the biosolids with green waste and use it as a fertiliser. Before biosolids can be used as a fertiliser they are tested to make sure they are safe from any contaminants that might affect people or the environment, such as heavy metals and pathogens.

Sometimes sewage ponds must be retired because the pond may be in an inappropriate place such as next to a river that floods into the pond, or the pond is no longer needed. Retirement means the pond is filled in with soil or stays as an unused wetland. The area is either abandoned, integrated into surrounding land uses such as forestry or agriculture, or they can be made into recreational zones.

Picture 2: Removing biosolids from a sewage treatment pond.

Local councils and an environmental consultancy are developing a ‘Lower North Island Biosolids Composting Strategy’. It has been requested that Rangitāne undertake a research program to support this strategy development.

Ministry for the Environment
Manatū Mō Te Taiao

LOWE Environmental Impact

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