BIOSOLIDS RESEARCH IN NEW ZEALAND – WHAT'S NEW?

J. Horswell, E. Langer (Scion), A. Van Schaik (ESR), V. Baker (ESR); G. Gielen (Scion), A. Leckie (Scion), M. Dennis (Scion); L. Tremblay (Cawthron Institute); C. Ross (Landcare Research), J. Cavanagh (Landcare Research), J. Ataria (Cawthron Institute), B. Robinson (Lincoln University), M. Ross (Whenua.biz); G. Northcott (Northcott Research Associates), J. Xue (Scion).

ABSTRACT

Currently, landfilling of biosolids is practiced by the majority of local authorities due to perceived and real uncertainties around social and cultural acceptability and risk of alternative disposal methods. There is a strong scientific case that application to land is a sustainable option, because biosolids are carbon-rich and contain high concentrations of valuable nutrients that can be used to bolster soil carbon reserves, thereby reducing dependence on artificial fertilisers. However, this approach is also potentially the least acceptable to the New Zealand public.

The land application of biosolids hinges on the outcomes of integrating both biophysical and social science. A sustainable long-term solution must balance these considerations in the context of New Zealand's soils, land use, demography and cultural setting/position. The Centre for Integrated Biowaste Research (CIBR), a predominantly Government funded research programme, has been characterising the environmental risks arising from application of biosolids in different land management options and to integrate this knowledge with the social, cultural and economic considerations.

KEYWORDS

Biosolids, sustainable, social, cultural, triclosan, vermicompost

1 INTRODUCTION

Waste management is crucial to our ability to live sustainably. New Zealand produces nearly 700,000 tonnes of organic waste each year more than 60% of the total waste stream going to landfill (Ministry for the Environment, Indicator update, October 2012; INFO 654). This organic, biodegradable waste includes sewage sludge, septic tank waste, food waste, green waste and greywater, as well as organic industrial and agricultural waste. The burden on the environment and the dollar cost to councils is increasing with resource consent applications and the physical act of burying the material. These wastes are carbon-rich and generally contain high concentrations of valuable nutrients which, if properly treated and/or processed, can have added value through resource recovery. An example is the re-use of organic wastes as a sustainable soil conditioner that has the potential to provide valuable physical (e.g. increased water holding capacity, infiltration and aeration), biological (e.g. beneficial organisms) and chemical (e.g. essential elements and plant nutrients and ability to mitigate chemical contaminants) attributes.

For many Territorial Local Authorities (TLA's) organic waste management is regarded as a high priority issue and is accompanied by a growing body of national legislation and strategy (e.g., Waste Minimisation Act (2008), The New Zealand Waste Strategy: Reducing Harm, Improving Efficiency (MfE 2010), climate change policy and energy strategy) all of which press for better and more sustainable options than landfill. Landfilling is currently the preferred option for many of these wastes, in particular for the potentially more contentious, such as biosolids (treated or stabilised sewage sludge).

So what's blocking the path to greater Biowaste re-use? One of the main issues with re-using/re-cycling biowaste is that alternative solutions are not simple. The issues have challenged regulatory agencies worldwide.

Some organic wastes can also contain a range of micro-contaminants such as heavy metals, agrichemicals, pathogens, pharmaceuticals and personal care products, thus management requires technical guidance and regulation to ensure minimal environmental/public health risk and maximum value. Small communities face the extra challenges of producing low volumes of a variety of different organic wastes and finding a low-cost, low-tech 'whole' waste solution that can be easily managed within the community. Some communities have identified social and cultural concerns surrounding land application of biowastes, such as sewage sludge and septic tank waste.

In 2011, the two biosolids research programmes in New Zealand joined forces to create a more integrated and cohesive research effort – in April of this year The Centre for Integrated Biowaste Research (CIBR) was launched. Led by ESR, and in partnership with Scion, Cawthron Institue and Landcare Research, CIBR is a multidisciplinary collaboration between 10 New Zealand research institutes, universities and research partners dedicated to developing appropriate and sustainable solutions that maximise the benefits and minimise the risks of re-using biowastes. Underpinned by Government research funding from the Ministry of Business Innovation and Employment (MBIE), this virtual research centre aims to address critical gaps in New Zealand strategies related to biowastes in recognition of the "national good" value of research in this area

For the past three years, the CIBR has undertaken work in two case-study communities, to help find alternative biosolids disposal/re-use options that satisfy social, cultural, economic and environmental criteria. As well as the case-study approach CIBR has been undertaking focused biophysical science into the fate and effects of emerging contaminants and mixtures of contaminants, identified by the waste water industry as critical knowledge gaps. Here we will briefly describe some of the main findings from the last three years.

2 KAIKŌURA

The EarthCheck® benchmarked sustainable community of Kaikōura has approximately 1500 tonnes of biosolids (stabilised sewage sludge) that have been left to weather under a resource consent granted until 2016. With less only three years remaining on the consented biosolids storage, the Kaikōura District Council was keen to engage with the local community to explore and find acceptable re-use options. The CIBR undertook a case study in Kaikōura to investigate biosolids management options with the community. This section discusses the Kaikōura case-study process and findings:

- Characterisation of the Kaikōura biosolids (contaminants and nutrients);
- The community engagement process:
    - initial community engagement – key community stakeholder hui
    - personal interviews with key community stakeholders
    - second key community stakeholder hui to develop re-use options
    - environmental life cycle assessment and economic analysis and the third key community stakeholder hui
    - fourth hui with broader community;
- Outcomes from the community hui with recommended re-use options.

2.1 CHARACTERISATION OF THE KAIKŌURA BIOSOLIDS (CONTAMINANTS AND NUTRIENTS)

The case study's environmental and biophysical research was developed in response to a community need, expressed in early interviews and the first hui, to know more about the composition of the Kaikōura biosolids before making a decision on their re-use. The CIBR research team characterized the biosolids in terms of physiochemical properties.

2.1.1 NUTRIENTS AND CHEMICALS IN KAIKŌURA BIOSOLIDS

Kaikōura biosolids are similar to well-matured compost in nutritional values. Soil chemistry test results undertaken showed that the Kaikōura biosolids have high to very high levels of plant-available macro-nutrients (nitrogen, phosphorus, sulphur, potassium, calcium and magnesium) and some micro-nutrients (boron, copper, zinc and sodium). Cation exchange capacity is high, which indicates good retention of nutrients for both soil conditioning (improving the physical quality of soils) and as an organic fertiliser, and will also improve biological activity and water holding capacity. The biosolids are acidic (pH 4.1), hence liming will be required for plants intolerant of slight to moderately acidic soils (e.g. to raise the pH to about 6 for pasture). However, the biosolids would be a suitable growing medium or soil amendment for most native shrubs and exotic plantation trees.

2.1.2 COMPOSTED AND VERMICOMPOSTED KAIKŌURA BIOSOLIDS

A vermicomposting trial was conducted using Kaikōura and Taupō district biosolids to guide potential use of compost produced from green waste and Kaikōura biosolids (Wang et al., 2011). Taupō biosolids were included in this trial to provide a comparison, and to generate cross case study insights. A small community near Taupō was the second case study location for the CIBR research (see section 3).

Vermicomposting was found to improve the nutritional value of resulting compost (e.g. 30% increase in total nitrogen and 24% increase in total phosphorus). It stabilised some heavy metals (reduced availability of arsenic, cadmium, copper, nickel and zinc) and increased soil carbon and water holding ability.

A pot trial was conducted to investigate the nutritional value of the composts. The effects of Kaikōura and Taupō district biosolids and vermicomposted biosolids on seedling growth and heavy metal uptake by native (tōtara and mānuka) and exotic (radiata pine) tree species (Xue et al., 2012). The results showed that biosolids and vermicomposted biosolids increased seedling growth of both native and exotic species on a low fertility soil which had been taken from a pine forest skid site. Vermicomposted biosolids increased seedling growth of radiata pine, tōtara and mānuka more than the non-vermicomposted Kaikōura biosolids. Application of biosolids and vermicomposted biosolids at a rate of 400 kg nitrogen per ha had little effect on the uptake of heavy metals by both native and exotic species. The accumulation of biosolids-derived heavy metals in the soil was insignificant. This study indicated that both biosolids and biosolids vermicompost have good potential as a fertiliser and/or soil amendments for rehabilitation of degraded soils..

2.1.3 PATHOGENS IN KAIKŌURA BIOSOLIDS

Kaikōura biosolids were tested for the presence and range of pathogens and compared to USA, New South Wales (Australia) and New Zealand biosolids guidelines (NZWWA, 2003) (see Table 1). *Salmonella* were below the detection limit. *Escherichia coli* levels were low but due to one outlier (2000 MPN *E. coli*/g) the biosolids are classed as Grade 'B'. It is highly likely that if more testing was carried out 95% of the samples would fall within the Grade 'A' criteria of <100 MPN/ g. The full range of pathogens specified in the biosolids Guidelines for Grade 'A' quality were not tested for as their presence was considered unlikely. It is recommended that before a decision is made on the biosolids re-use, the pathogen content is analysed.

Table 1: Pathogen in Kaikōura biosolids presented alongside USA, New South Wales (Australia) and New Zealand biosolids guidelines.

Microorganisms	**U.S.A**		**New South Wales***	**New Zealand***	**Kaikōura biosolids**
	Class A	**Class A**	**Class B**	**Grade A**	
E. coli	N/A	N/A	N/A	<100 MPN/ g	680 MPN/g
Faecal coliforms	<1000 MPN/ g	<1000 MPN/ g	<2000000 MPN/ g	N/A	Not analysed
Salmonellae	<3 MPN/ 4 g	Not detected / 50 g		<1/ 25 g	Not detected / 25 g
Enteric viruses	<1 PFU/ 4 g	<1 PFU/ 4 g		<1 PFU/ 4 g	Not analysed
Helminth ova	<1/ 4 g	<1/ 4 g		<1/ 4 g	Not analysed

PFU = plaque-forming unit;

MPN = most probable number;
* New Zealand and New South Wales Grade/Class 'B' sludges have no limits for microorganisms.

2.1.4 ORGANIC CONTAMINANTS IN KAIKŌURA BIOSOLIDS

Organic and heavy metal contaminants are present in urban wastewaters at relatively low concentrations, but are concentrated in biosolids during wastewater treatment processes. Contaminants accumulate in the sewage sludge as they tend to concentrate in the solid fractions. International and New Zealand data on organic wastewater contaminants (OWCs) in biosolids and their fate and effects is insufficient to develop a suitable risk assessment under New Zealand conditions. However, there is little evidence to limit land application of biosolids for the purpose of rehabilitating degraded soils. The added benefits of nutrient input to facilitate vegetation and reestablishment of viable functioning topsoil can outweigh the potential risks arising from the presence of OWCs in the Kaikōura biosolids.

To date we have analysed a wide range of commonly prescribed pharmaceutical residues in Kaikōura biosolids representing 11 classes of medicinal drugs. Twenty seven out of a total of 65 individual pharmaceuticals were measured in Kaikōura biosolids. The pharmaceuticals measured in stockpiled Kaikōura biosolids were present at very low concentrations and were much lower than those reported in fresh biosolids from other countries, and from freshly produced biosolids (Table 2). The relatively low concentration of pharmaceutical residues within the Kaikōura biosolids is likely to have resulted from continued degradation during the extended period of storage and stabilisation. It is expected that the concentration of other OWCs within the stockpiled Kaikōura biosolids will have continued to decline during storage and stabilisation.

Our research to date indicates that the aged biosolids have no acute toxicity in earthworm standard tests. Earthworms are model organisms used internationally in ecotoxicity testing (Kinney et al., 2012). The fact that the stockpiled biosolids contain large numbers of earthworms strongly indicates that the material has negligible toxicity.

Table 2: Pharmaceuticals found in the stockpiled Kaikōura biosolids.

Pharmaceutical type	**Name**
Analgesic	Naproxen, Acetaminophen
Lipid regulators and statins	Fenofibrate
Psychiatric drugs	Carbamazepine
Antibiotics	Sulfamethoxazole, Ciprofloxacin
Beta blockers	Metoprolol, Propanolol

2.1.5 HEAVY METALS IN KAIKŌURA BIOSOLIDS

High amounts of trace elements such as heavy metals (zinc, copper etc.) can become contaminants and impact environmental health. Sources of heavy metals can be industrial (e.g. particularly in large towns/cities) and domestic (e.g. hot water cylinders and personal care products). Scientific research will enable a better understanding of how heavy metals behave in the environment.

There are no known industries which release heavy metals into the Kaikōura waste stream and hence any heavy metal contamination is likely to have come from domestic sources. Slightly elevated concentrations of cadmium and mercury, along with elevated copper and zinc concentrations (see Table 3) place the Kaikōura biosolids as Grade 'b'. Tests were not carried out on the bioavailability of these contaminant heavy metals (owing to the limited funding), hence their potential uptake and concentration in plants and fate in the environment is unknown. However, previous research within the CIBR programme suggests that this risk is low. The other potential contaminant heavy metals tested for were within Grade 'a' specifications in the biosolids guidelines (NZWWA, 2003).

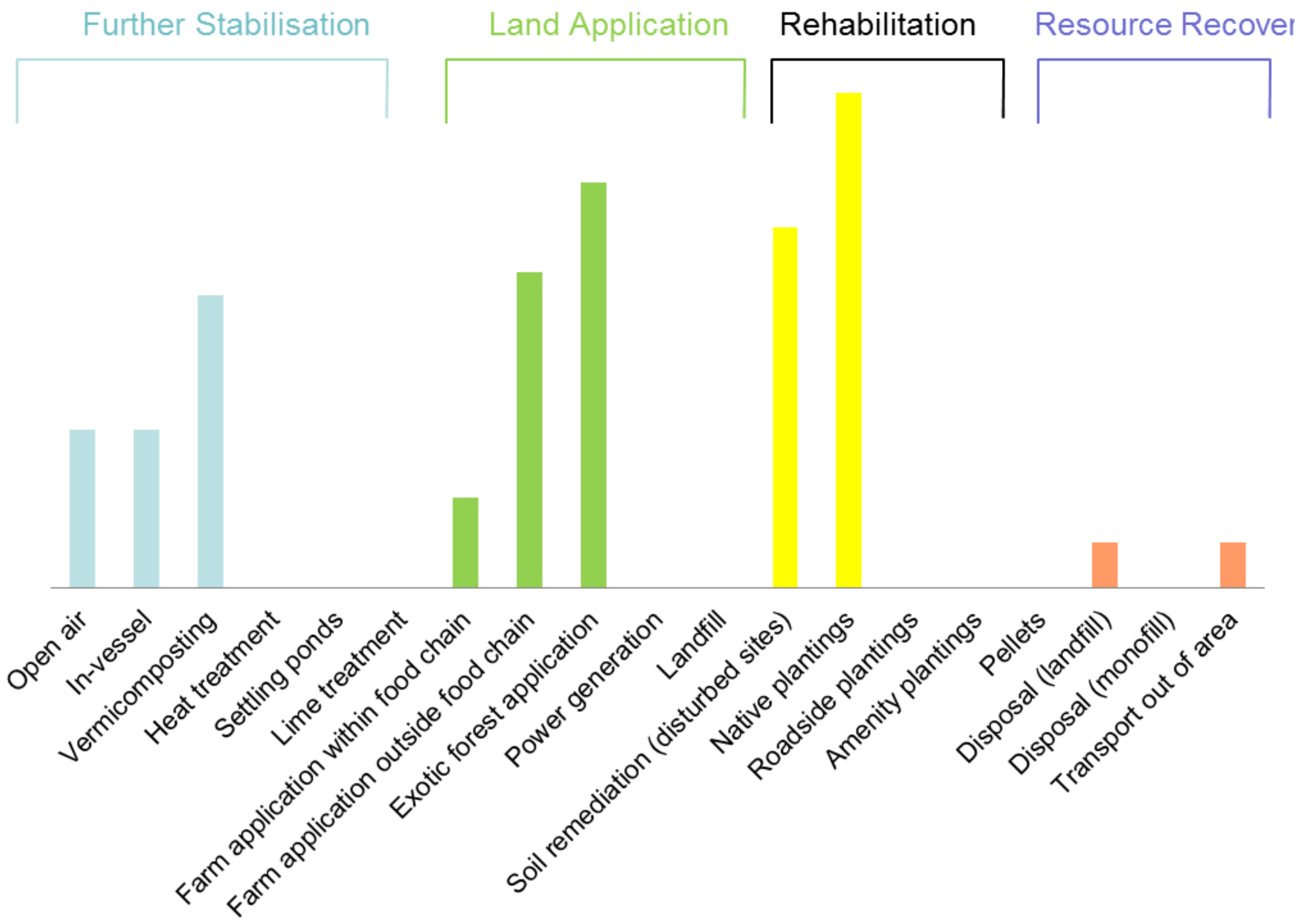
Table 3. Heavy metals in Kaikōura biosolids

Heavy Metal	**Kaikōura biosolids**	**NZ Biosolids Guideline limit concentrations (mg/kg)**	
		Grade A	**Grade B**
Cadmium	2.8	1	10
Chromium	32	600	1500
Copper	561	100	1250
Lead	96	300	300
Zinc	878	300	1500
Mercury	2.3	1	7.5

2.2 COMMUNITY ENGAGEMENT PROCESS

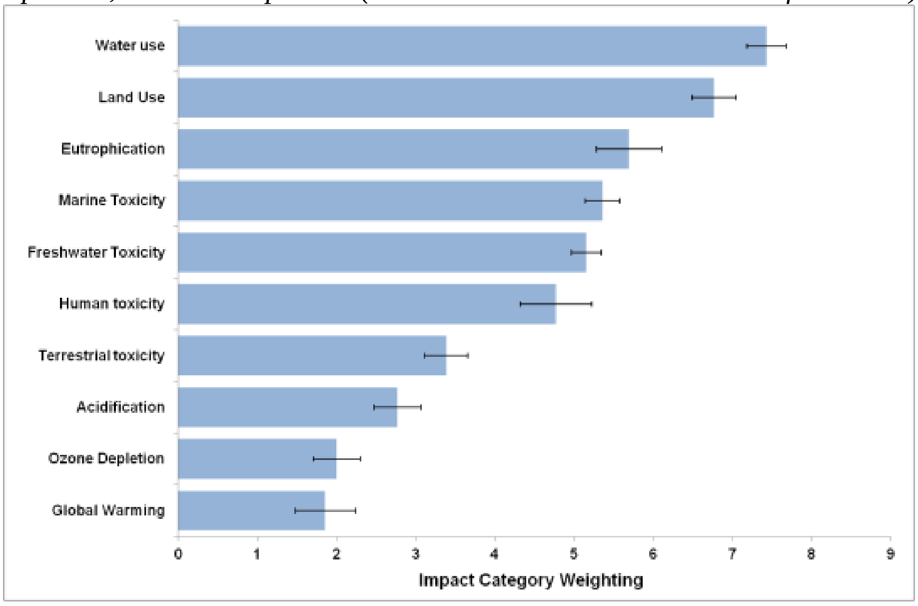
1. **Establishing key stakeholders -** first hui was held in Kaikōura (October 2009) to begin engagement with key stakeholders who have a direct interest in, or were likely to be affected by, the management of Kaikōura biosolids. Participants were invited via a mail out and follow-up phone calls to ensure participation. Participants included: representatives of tangata whenua, Te Korowai o Marokura (a community environmental action group), business operators, local government, commercial and recreational fishing and other environmental groups. The data collected proved a rich resource to identify 'key stakeholders', with suggestions spanning a cross section of the community
2. **Face-to-face interviews,** were conducted with key stakeholders to explore what they value about their environment, what they thought should be done with existing biosolids, and what concerns they had about the possible impact of biosolids re-use. This resulted in a refinement of biophysical science (e.g. inclusion of vermicomposting). Few of the key stakeholders had extensive knowledge about biosolids and how it should be managed, and almost all felt that whatever happened to it would depend on what was in the biosolids. Land application was the popular choice for managing the current stock-piled biosolids, with varied views of what would be the most appropriate means of achieving this. A number of concerns were raised including the cost of the solution, not wanting to transport the 'problem' elsewhere, and 'unknowns' around microbes, metals, chemicals, pharmaceutical and body-care product issues.
3. **Second community engagement Hui** (February 2011) was held with key stakeholders to select re-use options for the stockpiled biosolids and provide insights into community views on contaminants. The biophysical, social and cultural science undertaken to date was presented to inform stakeholders and aid decision-making. After presentation of the science results, a facilitated workshop session was held to enable key stakeholders to discuss a number of feasible options for their biosolids. Participants were asked to discuss the environmental positives and negatives, social and cultural positives and negatives, economics and feasibility of each of the options. A total of 19 options were presented to the community (further Stabilisation (6 options); land application (5 options); rehabilitation of land (4 options); resource recovery (4 options). Of the potential biosolids re-use or management options the following five were ranked highly (Figure 1):
    1. Further stabilisation – open air composting
    2. Further stabilisation – vermicomposting
    3. Land application - Farm application outside food chain;
    4. Land application - Exotic forest application
    5. Land application - Rehabilitation of disturbed sites with native plant species

Figure 1: Ranking of biosolids re-use options



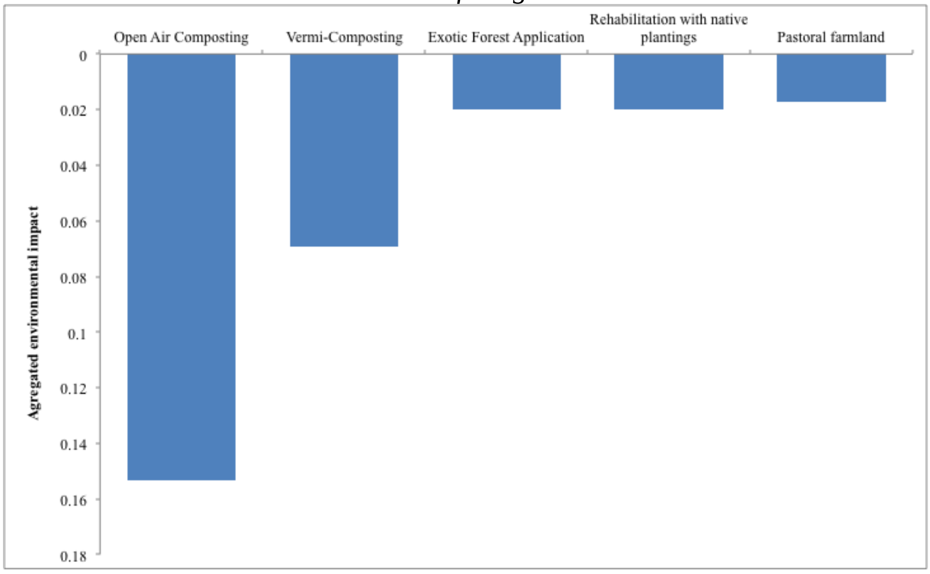
4. **Environmental Life Cycle Analysis (LCA) and Economic analysis** were undertaken during 2011 to provide stakeholders with supporting information for their decision-making. A community hui involving the district council, tangata whenua and community group representatives was held in Kaikōura in December 2011 to provide key stakeholder input to the analyses. Here we explained the environmental impacts quantified in the LCA study (e.g. global warming etc). Then each stakeholder was given ten votes, numbered one to ten that they could allocate to each of the impact categories to represent how important the different environmental impacts are to the Kaikōura community regarding the biosolids re-use options. Details of the environmental impacts and the scores are detailed in Figure 2. In addition to the voting, stakeholders were encouraged to record the reasons for their vote.

Figure 2: The environmental impact category weightings developed from voting. 10 = most important, 1 = least important (error bars are the standard error of the mean).



Detailed LCAs of the environmental impact of the biosolids re-use options were undertaken. The community weightings were integrated with the environmental impact calculations to derive a single score that described the overall environmental impact of the re-use options (Figure 3).

Figure 3: The aggregated environmental impact index for each of the re-use options presented relative to landfilling the waste.



5. **Cost Benefit Analysis -** A cost benefit analysis (CBA) was carried out to assess the relative net cost of each of the five preferred re-use options. Interviewing was also undertaken with 23 key community stakeholders to provide data for the cost/benefit analysis of the selected re-use options. For example ‘willingness to pay and use’ biosolids vermicompost was assessed, compared to the current open air composting of green waste (Table 4).

Table 4: Personal willingness to pay for biosolids vermicompost compared to current green waste composting (open air compost).

Biosolids Compost	***Personal willingness to pay***		***Willingness of community to pay***	
	Mean WTP	(min-max)	Mean WTP	(min-max)
Open Air Compost	$17	$0 - 30	$19	$5 - 30
Vermi Compost	$21	$0 - 30	$23	$5 – 40

6. **Final community engagement Hui** (March 2012) was held with the Kaikōura community. Extensive time and energy was put into inviting key stakeholders with follow-up phone calls to ensure their attendance. The biophysical, social and cultural science undertaken to date was presented in short presentations featuring key messages. Table 5 summarises the economic costs for each of the five options. The Kaikōura biosolids were classed as Grade 'Bb' with respect to pathogens and contaminants and this was discussed at length with most participants generally comfortable with land application (but not food chain) of a Grade 'Bb' product. After presentation of the science, a facilitated workshop session was held to enable key stakeholders to discuss the five options for their biosolids. A "station" for each option was set-up manned by a technical expert and a note taker. This facilitated an open forum between the community and the researchers. All views and opinions of the participants were recorded with respect to each option. Participants were asked to comment if they *support* or *do not support* each option. Key decision making information appeared to be the LCA analysis and the economic data.

Table 5: Summary costings for the 5 biosolids re-use options for the Kaikōura biosolids.

Option	***Time period***	***Net Cost***
Business as usual (not an option)		
1. Open air composting (IWK)	5 years	$36,500
2. Vermicomposting (IWK)	3 years	$45,700
3. Farm (non-food) application	Minimal non-food farm in the district	
4. Exotic forest direct application (Clarence forest)	6 weeks	$25,300
5. Application on native plantings	Very long time	Very high cost

Outcomes: The community participants supported biosolids application to exotic forest plantations, application to rehabilitate land to grow native plants and composting (both open air composting and vermicomposting) prior to being sold to the public. Although the exotic plantation application option received the most support the community favoured a multi solution approach with biosolids re-used in more than one option.

2.3 COMMUNITY RECOMMENDATIONS FOR BIOSOLIDS RE-USE

Kaikōura District Council took part in the entire case study from its inception to the fourth hui and received the community recommendations for preferred re-use. The biophysical research provided the characterisation information on the Kaikōura biosolids, carried out specific research on these biosolids and drew on the wealth of New Zealand and international research findings. The community provided well-considered and described input in the re-use option evaluation process. The integration of social, cultural, environmental and economic considerations as part of the engagement model gave the community a mechanism to weight (prioritise) their concerns, enabling the community and the council to make a more informed robust and transparent decision. Overall the CIBR integrated engagement process was very successful and has enhanced the level and quality of engagement and knowledge shared between council and community on biosolids and waste management. Similar forms of collaborative community engagement could be utilised by local government to build shared

3 MOKAI

Typical of many small communities in New Zealand is the settlement of Mokai (near Taupō). In contrast to Kaikōura, most of the settlement in Mokai is serviced by on-site septic tank systems. The biosolids created by this process are removed periodically and treated at the Taupō waste water treatment plant. The Mokai community has expressed a wish to explore sustainable options for management of their own waste and waste streams on-site. They are interested in potential solutions that fulfill the following criteria: low cost, technically robust, relatively simple and easily maintained with the potential for cost recovery – i.e. the product could be used to re-instate degraded land.

In this study we have investigated the potential of vermicomposting as a technology to produce a high value (Grade 'A') product for small isolated communities that have an interest in recycling/re-using their own waste.

An important consideration is the New Zealand Water and Wastes Association (NZWWA, 2003) biosolids guidelines for microorganisms and its impact on land use of the product produced by vermicomposting. Failure to meet Grade 'A' guidelines means that any application requires a quarantine period meaning valuable land is lost from cropping/pastoral use. With limited land availability this may dictate whether a process like vermicomposting is accepted by the community.

In addition the social/cultural science team has conducted a survey with all households in the Mokai community to:

- Provide increased awareness of the different types of cleaning and personal care products used by households, and the potential impact of these products on the environment;
- Increase understanding of the wastes produced by households, and how these are currently being disposed of or managed; and
- Gather information and perspectives on sewage and waste water systems used by households in rural communities such as Mokai.

3.1 VERMICOMPOSTING - PUTTING WORMS TO WORK, EXAMINING THE BIOLOGY AND CHEMISTRY BEHIND VERMICOMPOSTING.

3.1.1 MATERIALS AND METHODS

3.1.1.1 WASTES

Septic tank waste from the Marae and several house-holds in the area were collected and de-watered by belt press to approximately 25% solids. The bulking agents, palm fibre and tomato prunings, were collected over the course of two months from the commercial greenhouses within the community. Both bulking agents were dried and the tomato prunings were chipped to 6 mm to ensure the final vermicompost would be free of large debris. Dewatered dairy shed solids were collected from local dairy farms. This waste, along with the bulking agents is already currently used in large scale vermicomposting by the community and was used as a positive control (PC).

3.1.2 EXPERIMENTAL DESIGN

Four treatments were used; a positive control (dairy shed solids + palm fibre + tomato prunings + worms (PC)), a negative control (septic tank waste 50% + palm fibre + tomato prunings + no worms (NC)), a low rate of septic tank waste treatment (septic tank waste 30% + palm fibre + tomato prunings + worms (LST)) and a high septic tank waste treatment (septic tank waste 50% + palm fibre + tomato prunings + worms (HST)). Proportions are listed in Table 6. The wastes were mixed with the bulking agents to an optimum C:N ratio for vermicomposting (C:N = 25) (Ndegwa and Thompson, 2000). A high carbon to nitrogen ratio helps the worms break down their bedding and food slowly so they don't produce too much heat as this would kill the worms. The choice of bulking agents was one of convenience as the two materials were readily available in the community, and had the right qualities in that they encouraged worm activity i.e. high water absorbency, 'bulky' and with a high C:N ratio. The vermicomposting units are show in Figure 4.

Table 6: Vermicomposting trial treatments

Treatment	**Bulking Agent 1**	**Bulking Agent 2**	**Waste**	**Worms**
Negative Control (NC)	Palm fibre 40%	Tomato Pruning's 10%	Septic Tank 50%	No
High Septic Tank Waste (HST)	Palm fibre 40%	Tomato Pruning's 10%	Septic Tank 50%	Yes
Low Septic Tank Waste (LST)	Palm fibre 60%	Tomato Pruning's 10%	Septic Tank 30%	Yes
Positive Control (PC)	Palm fibre 60%	Tomato Pruning's 10%	Dairy Shed 30%	Yes

Figure 4. Custom Vermicomposting Units

All treatments were mixed weekly to ensure adequate aeration and sampled fortnightly for a range of chemical and biological parameters (Dehydrogenase enzyme activity, Total *Escherichia coli* (*E.coli*), phosphate (Olsen P), nitrate and ammonia).

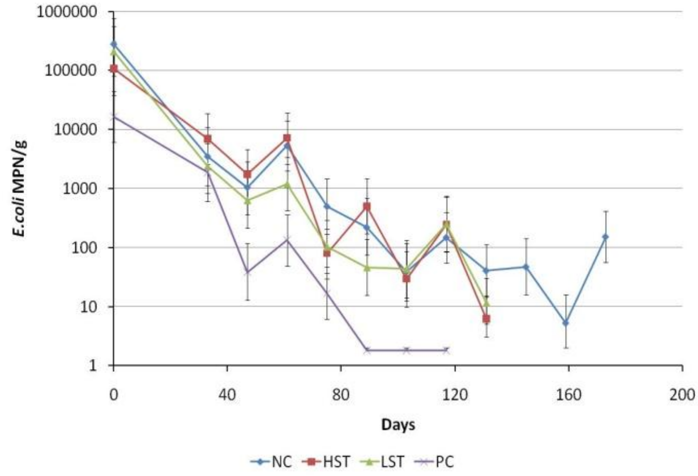
3.2 RESULTS AND DISCUSSION

3.2.1 *E.COLI* DURING THE VERMICOMPOSTING PROCESS

E.coli was used to monitor the progress of the vermicomposting process. Changes in the concentration of *E.coli* in the different treatments over the course of the experiment are shown in Figure 5. The values showed a gradual decline for all the treatments over time. While there was no significant difference between the three septic tank waste treatments with numbers reaching the Grade A biosolids guideline limit (Table 7) after 131 days, the *E.coli* concentration in the positive control treatment reduced to non-detection levels after 89 days. It appears the time taken to reach the Grade A guideline limits for *E.coli* had not been affected by the presence of worms and is most likely a result of natural composting processes. The increased time taken by the septic tank waste treatments to reach the guideline limits compared to the positive control is most likely related to the quality of the feed stock, with the positive control being substantially lower in total organic matter and more importantly disolved organic carbon (DOC).

Variability in *E.coli* concentration was significant in all treatments (Figure 5), at times up to a log 2 difference was observed between time periods and between replicates. This is most likely to be related to the mixing that was performed during each sampling, re-distributing the microflora and food sources, and re-aerating the compost.

Figure 5. Changes in E.coli MPNs during the vermicomposting process in the Negative Control (NC), High Septic Tank (HST), Low Septic Tank (LST) and Positive Control (PC) treatments.



3.2.2 INDICATOR MICROORGANISMS/PATHOGENS

A summary of the treatments with respect to the guideline limits for microorganisms are shown in Table 7. Though a significant drop in Helminth Ova was observed, the concentrations were in most cases a hundred times greater than the limit concentration. *Campylobacter* spp concentration was also a concern as the treatments containing worms maintained a healthy population (>28000 MPN / 25 g) of this genus (at least three separate species were characterised, *C. coli, C. lari and C. jejuni*), while no Campylobacter spp were detected in the negative control.

Table 7. Indicator Microorganisms/Pathogens in the Septic Tank Waste and subsequent products

Microorganism	**NZWWA Guideline Limits Grade A**	**Septic Tank Waste**	**Final Products (Compost & Vermicompost) and days taken to stabilize**		
			Negative Control 187 days	**High Septic Tank 131 days**	**Low Septic Tank 131 days**
E.coli	<100 MPN/ g	2.3×10^4 – 2.4×10^5	4 – 14	ND – 14	ND – 33
Salmonella spp	<1 / 25 g	ND – 23	ND	ND	ND – 5.3
Campylobacter spp	<1 / 25 g	1200 – >2800	ND	>28000	>28000

Helminth Ova	<1 / 4 g	700 – 1900	*No Data Available*	60 – 250	84 – 250

3.2.3 NO_3^--N & NH_4^+-N

Changes in the concentration of NO_3^--N and NH_4^+-N in the different treatments over the course of the experiment were monitored (Figures 6 and 7, respectively). As the primary effect of earthworms on N-cycling is to increase the rate of organic-N mineralization (Parkin and Berry, 1994), it was expected that there would be an increase in NO_3^--N during the course of the experiment. This was the case for all treatments though the rate was significantly different for each. After only 75 days the positive control had stabilized at 5000 mg/kg (Figure 6) which indicated that vermicomposting had reached its conclusion. The septic tank/worms treatments continued to show incremental increases while the high septic tank waste treatment lagged behind the low septic tank by 14 days. At the final sampling the levels were 2500 mg/kg and 3500 mg/kg respectively. The negative control showed a slow increase in NO_3^--N until stabilisation at 300 mg/kg at 145 days, significantly lower than the other treatments.

By day 47 the NH_4^+-N concentrations had stabilised for all treatments at around the same level (between 20-30 mg/kg) (Figure 7) and no significant changes occurred after this. The rapid loss of NH_4^+-N during the first few weeks may be attributed to a combination of volatilisation and nitrification. 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 (Masciandro et al., 2000). Earthworm casts are known to be enriched in mineral-N (Parkin and Berry, 1994) and this may account for the significant difference between the negative control and the other treatments with regards to NO_3^--N concentration.

Figure 6. Changes in 2M KCl extractable NO_3^--N during the vermicomposting process in the Negative Control (NC), High Septic Tank (HST), Low Septic Tank (LST) and Positive Control (PC) treatments.

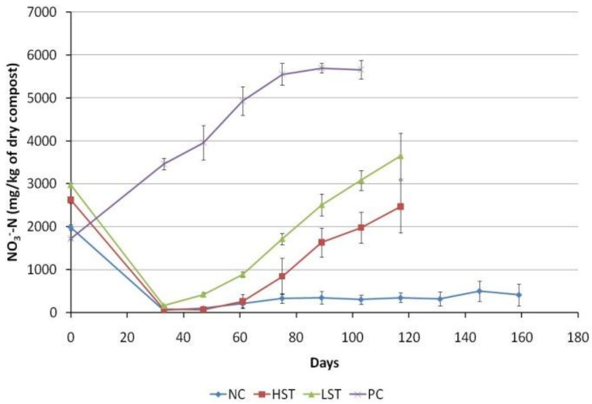
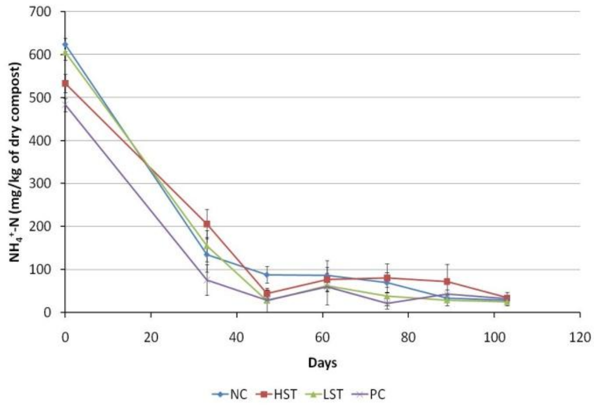


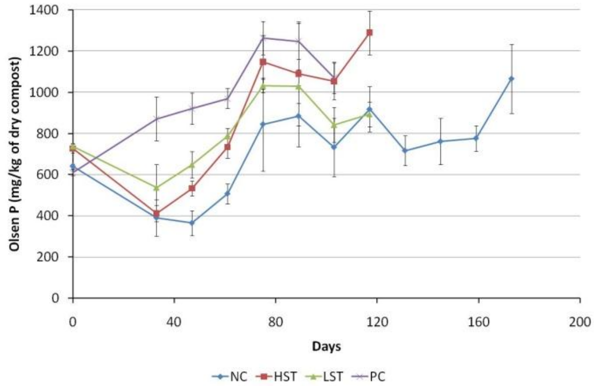
Figure 7. Changes in 2M KCl extractable NH_4^+-N during the vermicomposting process in the Negative Control (NC), High Septic Tank (HST), Low Septic Tank (LST) and Positive Control (PC) treatments.



3.2.4 OLSEN P

In general all treatments showed increases in Olsen-P until day 89 after which a steady state was achieved (Figure 8). As Olsen-P represents a significant portion of the total mineralisable P, it was used in this study as a surrogate when looking at the mineralisation of organic-P during composting. The negative control had a generally though not significantly slower rate of mineralisation. Worms are efficient at mineralising organic-P from a wide range of organic materials (Ghosh et el., 1999) as observed by the increase in rate of Olsen-P generation in the treatments that included worms.

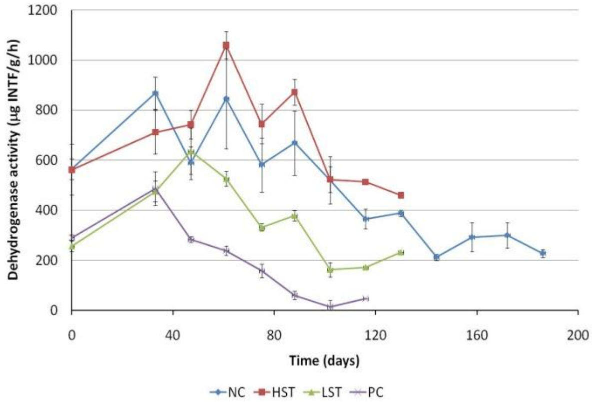
Figure 8. Changes in Olsen-P during the vermicomposting process in the Negative Control (NC), High Septic Tank (HST), Low Septic Tank (LST) and Positive Control (PC) treatments



3.2.5 DEHYDROGENASE

Dehydrogenase activity in soils and other biological systems has been used as a measure of overall microbial activity (Garcia et al., 1997), since it is an intracellular enzyme related to the oxidative phosphorylation process (Trevors, 1984). For the positive control the activity peaked at 33 days then tracked downwards consistently until around 89 days where it stabilized at a relatively low activity (Figure 9). Low DOC may account for generally lower activity in this treatment. The Low septic tank waste treatment peaked at day 47 then followed a similar trend but stabilised at a much higher activity which matches well with DOC.

Figure 9. Changes in Dehydrogenase activity during the vermicomposting process in the Negative Control (NC), High Septic Tank (HST), Low Septic Tank (LST) and Positive Control (PC) treatments.



3.3 CONCLUSIONS

Vermicomposting has the potential to be used for the transformation of septic tank waste - via the gut of the worm - into a more socially and culturally acceptable resource. It is effective in stabilizing nutrients and reducing pathogen loadings in the final product and the technology is highly recommended as a low cost, simple and sustainable alternative for the community. However, *E. coli* reduction did not relate well to removal of pathogens such as *Campylobacter* and helminth ova. Pasturing temperatures cannot be achieved during vermiculture as worms are sensitive to thermophile temperatures, thus for wastes containing high levels of pathogens (such as raw sewage or septic tank waste), pre-pasteurisation or further composting may be required to produce a Grade A product under current biosolids guidelines.

3.4 MOKAI HOUSEHOLD SURVEY

The Mokai household waste survey was aimed at providing a clearer picture of the different sewage and other waste related outputs produced in the local area. These waste streams include grey water and septic tank sludge and liquids. Greater scientific knowledge, combined with traditional cultural knowledge, household and business practices will inform stronger frameworks for kaitiakitanga, tino rangatiratanga, and protection of human health and the environment (Kawharu ed. 2002). The survey wanted to promote awareness in communities about what is disposed of down the drain and to better understand what implications exist for human and environmental health, and how these risks and uncertainties can be best managed today and in the future.

We asked adult members of all households in the Mokai area to participate in a survey about their household wastes. A total of 95 questionnaires were distributed to potential participants in December 2012. Entry into a draw for a Christmas ham and a bottle of champagne was offered to the Mokai households as an incentive to complete the survey. A total of 33 questionnaires were hand delivered to all dwellings located in the Mokai village area, including those on neighbouring Tuaropaki Trust land. This was based on identifying physical addresses from aerial and street maps. Another 37 questionnaires were distributed following enrolment advice from school staff. Children attending the local Mokai pre-school and Tirohanga primary school were provided with a questionnaire to take home to their guardians and parents. This method had the lowest return rate and we think that many households may have already responded to the survey delivered to their dwelling. Finally an additional 25 copies of the survey were distributed by the organisers of a hui held at Mokai Marae during the survey period. Questionnaires were anonymous and respondents were asked not to provide their name or any identification details.

A total of 61 of the 95 questionnaires distributed to both the visitors and household residents, were returned by the due date of 10 December, giving a 64% response rate. Having a local person (Caroline Waaka) doing the face to face distribution and collection of the survey was important in gaining such a high response rate.

The survey data was supplemented by data from two focus groups to help interpret and contextualise the survey results. Two focus groups were held at Mokai on the 30th and 31st May 2013, with three community members attending each session; a total of 6 community participants in total. The focus groups were intended to familiarise participants with the survey data, check that the findings were robust and begin to talk about the implications of the survey findings.

3.4.1 RESPONDENT CHARACTERISTICS

Approximately 74% of the respondents were female. Over two thirds (68%) of the respondents identified their ethnicity as Māori. About 62% of the respondents reported their age as between 30 – 59 years old.

3.4.2 MOKAI HOUSEHOLD CHARACTERISTICS

We found that 55% of respondents had lived in their house for 4 years or less, and that 38% owned their house. For many, the average total annual household income for Mokai was less than half the Waikato area average of $66,612 per household per annum (http://www.waikatoregion.govt.nz), with 82% of Mokai households giving their total income for the previous year as less than $50,000.

The number of permanent occupants per household that participated in the survey was averaged to give 3.5 occupants per household. However, the majority of households (79%) usually had visitors come to stay during weekends and holidays. This survey did not gather the viewpoints of visiting whanau, or the day workers and visitors to Mokai.

3.4.3 FINDINGS AND HIGHLIGHTS

All homes in the Mokai community are connected to a septic tank rather than a reticulated system, but not all householders were aware of this. A large majority (79%) of households confirmed they were on a septic tank, while the remaining 21% answered 'other' or 'don't know'. Furthermore many respondents (30%) did not know how old their septic tank was, or how long since it had last been cleaned out (33%). Very few households (19%) felt that they had enough information about which cleaning, laundry and personal care products are harmful to their septic tank system, confirming an important knowledge gap that the CIBR is working to address. Most household respondents (62%) rated their 'environmentally friendliness' as average or greater than average. The most common actions by households to help the environment are recycling (79%), reduced energy use (74%) and buying refills (72%). However, the results about household spending patterns in Mokai confirmed other New Zealand research findings, that 'cost' is a more important concern that may override 'environmentally friendliness' as a factor when making purchasing decisions. Low income is a factor that can limit a household's ability to purchase more environment friendly products, which can sometimes be 50% more expensive than conventional household products.

Household respondents reported that 'advertising' (53%) and 'green labelling' (47%) were considered as their main indicators if a product was 'environmentally friendly' or not. Similar to other New Zealand and international research, women are the main household shoppers.

3.4.4 CONCLUSIONS

We conclude that the survey has given a valuable snapshot of the Mokai community and their attitudes, values and practices around managing household waste. There is little research on Māori values and attitudes to waste (Pauling and Ataria 2009). This survey makes an important contribution and highlights some important issues for rural communities in managing waste.

All Mokai homes are on a septic tank, rather than reticulated system, but there seemed low awareness, some knowledge gaps, and some need for cleaning and maintenance. Lack of awareness of sewage and water systems is typical across urban and rural populations, given that these valuable infrastructure services are often hidden below the ground (PCE 2000; PCE 2001), and that sewage is one of many services that are often out of sight out of mind (Beecher et al 2005; Shove and Warde 2002).

The environmental and health consequences of this lack of awareness may be greater for rural communities with the impacts of system failure more immediate and with possibly greater consequences for the receiving environment, the productive sector, and recreational activities. Septic tank maintenance and care is a common problem for many rural communities with a number of district council's considering how to better coordinate septic tank services, rather than leaving this important responsibility solely with individual households (Gisborne District Council, 2013).

4.0 EMERGING ORGANIC CHEMICALS – FILLING THE KNOWLEDGE GAPS

Triclosan (5-choloro-2-(2,4-dichlorophenoxy) phenol; TCS) is a broad spectrum antimicrobial agent, which is used in a wide variety of personal care products including deodorants, hand soaps, toothpaste, textiles, laundry detergents, antiseptics, shower gels and cleaning agents. Household products containing triclosan are typically discarded into the sewage system.

A major pathway for the movement of organic contaminants such as TCS to the environment is through the land application of biosolids, a common practice in many countries. Pharmaceutical compounds are specifically designed to alter both the biochemical and physiological functions of biological systems in humans and animals (Daughton and Ternes, 1999). These features can however unintentionally affect soil and aquatic animals should their habitats become contaminated with these chemicals. What remain unknown are the possible effects of long-term exposure to compounds such a TCS. Moreover, we know that biosolids contain a suite of contaminants including heavy metals which can be present at concentrations significantly higher than pharmaceutical compounds primarily because they are not degraded in the WWTP. There is an international knowledge gap on whether low concentrations of numerous compounds in biosolids combine to produce synergistic/antagonistic/additive ecotoxicological effects on ecosystems (Daughton and Ternes, 1999; Daughton, 2003; Dorne *et al*., 2007).

Taking a first step to a holistic understanding of the toxicological effects and impacts of complex mixtures of contaminants is challenging, but is critical to assessing the potential risks that chronic low-level exposure may present to the environment. In this study we investigated the effects of metal + organic mixtures on a range of soil biological indices (e.g. soil enzymes, sensitive microbial biosensors, and *Rhizobium).*

4.1 METHODS

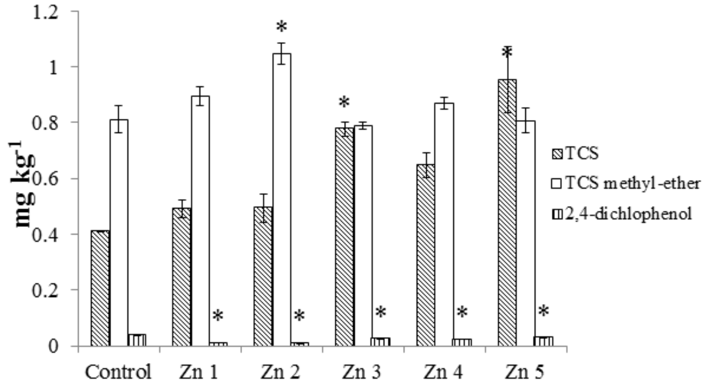
*S*mall lysimeters were established using field soils historically contaminated with copper and zinc at a range of concentrations (Cu: 50, 120, 300, 750, 2000 mg/kg; Zn: 70, 160, 400, 1000, 3000 mg/kg), with the addition of TCS at 5 mg/kg and 50 mg/kg. The degradation dynamics of TCS in the presence of increasing concentrations of heavy metals was measured, as well as potential additive/synergistic effects on the soil microbial community.

4.2 RESULTS

4.2.1 TRICLOSAN CHEMISTRY

In the control soils (control TCS low– 5mg/kg; control TCS high – 50 mg/kg), TCS was rapidly degraded and < 6 % of the parent compound remained in the soils after 6 months. The major degradation product found in the soils was methyl-TCS. For both Zn and Cu, as the metal concentration increased, there was a reduction in both transformation and degradation of TCS (Figure 10). Thus, the presence of a co-contaminant such as a heavy metal may affect the microbial communities ability to rapidly degrade TCS and therefore increase potential impacts on terrestrial organisms such as soil microbes.

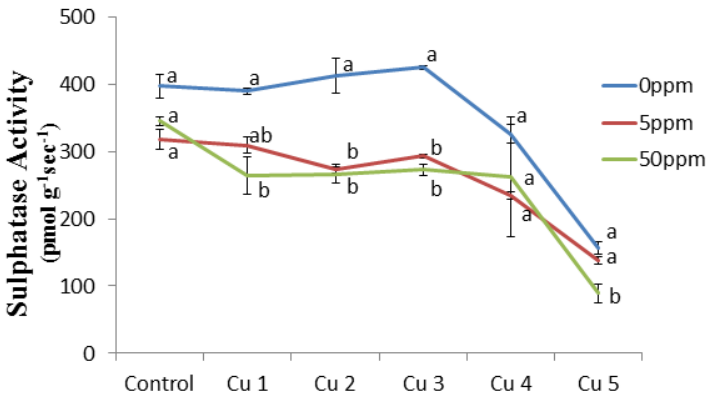
*Figure 10. Concentration of triclosan, methyl-triclosan and 2,4-dichlophenol (mg kg-1) remaining after 6 months in the soils spiked with 5 mg kg-1 triclosan and zinc at varying concentrations. Error bars represent standard errors. * indicates significant difference from control ($p < 0.05$).*



4.2.2 IMPACTS OF TRICLOSAN ON SOIL HEALTH INDICATORS

For some of the properties measured, there was a significant (P = 0.05) impact on activity from exposure to TCS (Figure 11) with no other co-contaminant present. Sulphatase activity in the "control – no metal and no TCS" was significantly higher than in the "control TCS low– 5mg/kg" and "control TCS high – 50 mg/kg" treatments (Figure 11). Activity was not significantly impacted by the presence of the metal co-contaminant until a 'tipping point" was reached where enzyme activity declined rapidly (Figure 11). For the 50 mg TCS kg^{-1} treatments, there was significantly less (P = 0.05) sulphatatse (Figure 11) and phosphatase (data not shown) activity in the highest Cu treatment when compared to the controls where no TCS is present, suggesting a possible synergistic effect of the presence of co-contaminants. This trend was also observed for sulphatase activity in the Zn lysimeters (data not shown).

Figure 11. Sulphatase enzyme activitie in relation to total soil copper treatment in soil spiked with 0, 5 and 50 mg/kg TCS. Error bars represent standard error. Values sharing the same letter are not significantly different (p < 0.05).



4.3 CONCUSIONS

Our preliminary data also suggest that the presence of numerous compounds in biosolids may combine to produce synergistic or additive ecotoxicological effects on the soils ecosystems, however further work is required to confirm this hypothesis.

5.0 CONCLUSIONS

Despite having science-based regulations or guidelines to facilitate beneficial re-use of many organic wastes (e.g. Guidelines for the Safe and Application of Biosolids to Land in New Zealand, New Zealand Standard for Composts, Soil Conditioners and Mulches (NZS 4454:2005)), progress has been slow towards achieving the NZ Waste Strategy target of improving the efficiency of resource use and diversion of organic wastes from landfill. In part this is because there is insufficient understanding of the risks with some wastes and there is significant uncertainty with regulator, iwi and community concerns regarding how much of any contaminant to allow on land. Limited knowledge on soil limit concentrations for some of the new and emerging contaminants, as well as social and cultural concerns can be barriers to biowaste re-use under the resource consenting process; especially for contentious wastes such as biosolids.

The integration of environmental, cultural, social science, life cycle assessment (LCA) and cost benefit analysis (CBA) can give decision-makers and their communities confidence and a protocol to balance environmental, economic, social and cultural factors to increase biosolids use. The methodology developed by this research programme provides a framework for biosolids re-use decisions that can potentially provide a basis for regional land use planning, national guidelines and policy directions.

The programme is also continuing to provide new knowledge on end-user driven research gaps, such as emerging organic contaminates. The outcome of this research will be to enhance our understanding of key soil properties and environmental conditions that determine contaminant bioavailability, fate and effects and how these can be manipulated to beneficially apply biosolids to soils in a sustainable way that also protects environmental and human health.

ACKNOWLEDGEMENTS
The New Zealand Ministry of Business, Innovation and Employment is acknowledged for funding the principle content of this research programme, and the Kaikōura District Council and the Sustainable Initiatives Fund Trust is acknowledged for financing the Life Cycle Analaysis.

Thank you to our case study communities (Iwi/local government etc) in Kaikōura and Mokai for their invaluable contribution to this research programme

REFERENCES

Beecher, N., Harrison, E., Goldstein, N., McDaniel, M., Field, P. and Susskind, L. (2005) Risk perception, risk communication, and stakeholder involvement for biosolids management and research. Journal of Environmental Quality, 34, 122-128.

Daughton, C. G. 2003. Pollution from the combined activities, actions and behaviours of the public: Pharmaceuticals and personal care products. SETAC News 14: 5-15.

Daughton, C. G., Ternes, T. A. 1999. Pharmaceuticals and personal care products in the environment: Agents of subtle change? Environmental Health Perspectives 107: 907-938.

Dorne, J. L. C. M., Skinner, L., Frampton, G. K., Spurgeon, D. J. 2007.Human and environmental risk assessment of pharmaceuticals: differences, similarities and lessons from toxicology. Analytical and Bioanalytical Chemistry 387: 1259-1268

Fertility of Soils 32: 479-483.

García, C., Hernández, T. & Costa, F. (1997). Potential use of dehydrogenase activity as an index of microbial activity in degraded soils. Communications in Soil Science and Plant Analysis 28: 123-134.

Ghosh, M., Chattopadhyay, G.N. and K. Baral. (1999). Transformation of phosphorus during vermicomposting. Bioresource and Technology 69: 149-154.

Gisborne District Council (2013) Your Septic Tank: What You Need to Know. Gisborne.

in the assessment of the response of soil to vermicompost and inorganic fertilisers. Biology and

Kawharu, M (editor) (2002) Whenua: Managing Our Resources. Reed Publishing Ltd: Auckland.

Kinney C.A., Campbell B.R., Thompson R., Furlong E.T., Kolpin D.W., Burkhardt M.R., Zaugg S.D., Werner S.L.H., Anthony G. (2012). Earthworm bioassays and seedling emergence for monitoring toxicity, aging and bioaccumulation of anthropogenic waste indicator compounds in biosolids-amended soil. Science of the Total Environment 433:507-515.

Masciandaro, G., Ceccanti, B., Ronchi, V., Bauer, C. (2000). Kinetic parameter of dehydrogenase

Ndegwa, P. M., Thompson, S.A. (2000). Effects of C-to-N ratio on vermicomposting of biosolids. Bioresource Technology 75: 7-12.

New Zealand Standard: Composts, Soil Conditioners and Mulches. NZS 4454:2005.

NZWWA. (2003). Guidelines for the safe application of biosolids to land in New Zealand. New Zealand Water and Wastes Association, Wellington, New Zealand.

Parkin, T.B. and E.C. Berry. (1994). Nitrogen transformations associated with earthworm casts. Soil biology & biochemistry 26: 1233-1238.

Parliamentary Commissioner for the Environment (2000) Ageing pipes and murky waters. Urban water system issues for the 21st Century. Wellington.

Parliamentary Commissioner for the Environment (2001) Beyond Ageing Pipes: Urban water systems for the 21st Century. Wellington.

Pauling, C., and Ataria, J. 2009. Tiaki Para: A Study of Ngai Tahu Values and Issues Regarding Waste. Landcare Research Science Series. No. 49. 42 pp. Landcare Research Ltd, New Zealand.

Shove, E., and A. Warde. (2002) "Inconspicuous consumption: The sociology of consumption, lifestyles, and the environment." Sociological Theory and the Environment: Classical Foundations, Contemporary Insights: 230-251.

Trevors, J.T. (1984). Dehydrogenase activity in soil: A comparison between the INT and TTC assay. Soil Biology and Biochemistry 16:673-674.

United States Environmental Protection Agency (2002). Biosolids Technology Fact Sheet: Use of Composting for Biosolids Management.

Wang, H., Heaphy, M.J., Ross, M., Xu, K., Unsworth, D.E. (2011). Vermicomposting biosolids with waste biomass – preliminary results. Pp 89-95. in: Proceedings of the 2011 New Zealand Land Treatment

Collective annual conference, Wang, H., Heaphy, M. (ed.). 23-25 March, Palmerston North, New Zealand.

Xue, J., Graham, D., Ross, M. (2012). Response of radiata pine and tōtara seedlings to the addition of biosolids and vermicomposted biosolids under glasshouse conditions. In Proceedings of the 2012 New Zealand Land Treatment Collective annual conference, Gielen, G., Heaphy, M. (ed.). 28-30 March, Tauranga, New Zealand.