

Guidelines for Beneficial Use of Organic Materials on Productive Land



Centre for Integrated Biowaste Research



Ministry for the
Environment
Manatū Mō Te Taiao



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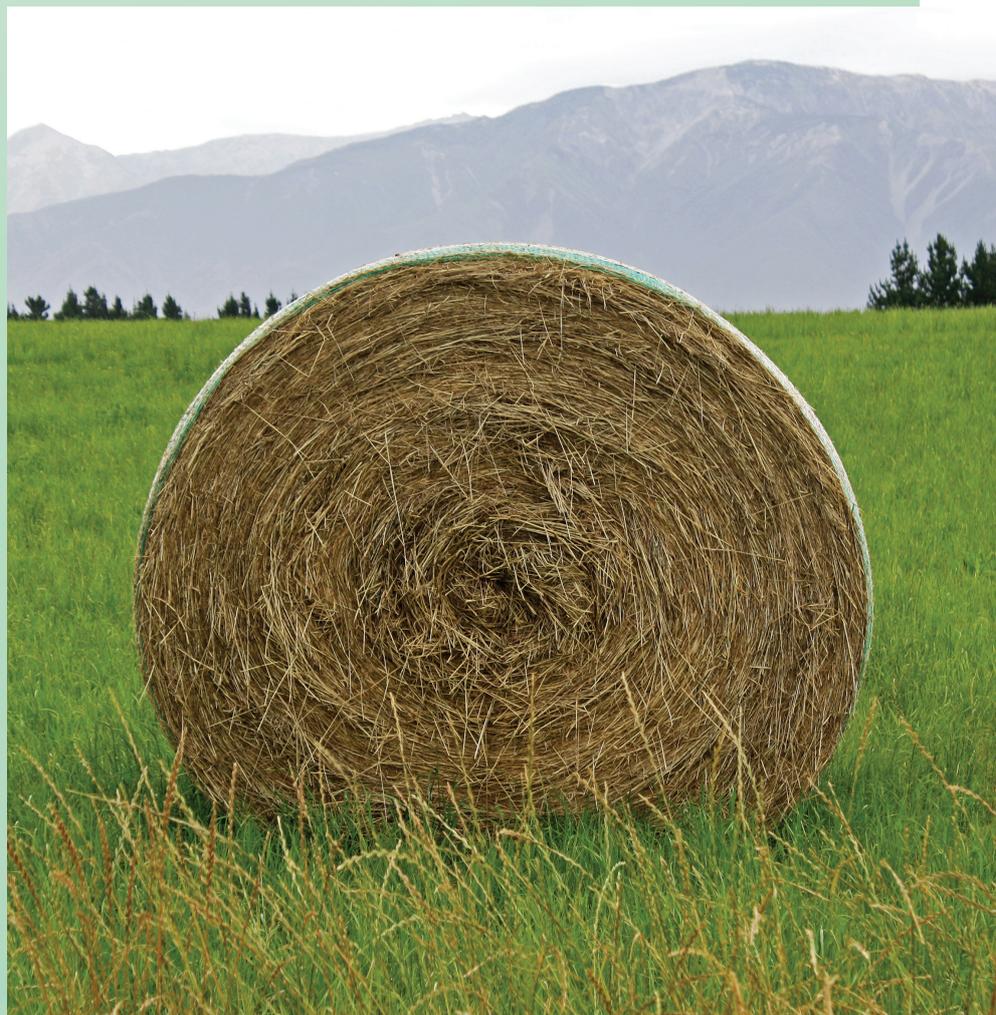
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Volume Two
TECHNICAL MANUAL

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1 INTRODUCTION

This section introduces supporting technical information.

This technical document provides background information in support of national guidance on the application of quality organic waste products to existing soils as fertiliser and/or conditioning agents to promote a more consistent approach to the management and benefit from using these materials throughout New Zealand.

1.1 WHAT ARE ORGANIC MATERIALS?

1.1.1 INCLUSIONS

The *Guide* applies to products made from organic materials or mixtures of organic materials that have been processed to make them safe for further use. The product quality and management of these materials should fully conform to the requirements of the *Guide*. Raw organic materials, often a waste product from other activities, which are suitable to make these products include:

- ◆ household organic wastes (food waste, green waste);
- ◆ paper and cardboard;
- ◆ organic wastes from the secondary sector, such as meatworks wastes;
- ◆ dead stock that do not pose a security risk;
- ◆ manures;
- ◆ sewage sludge;
- ◆ pulp and paper waste; and
- ◆ biodegradable nappies and sanitary items.

Such products will have notable fertilising and soil conditioning properties as a result of their nutrients and organic content. They also contain organic matter (carbon), which improves soil structure, water storage and microbial health.

The product inclusions for this guide are not determined by the amount of liquid contained within the products. It is acknowledged that different industries use their own definitions and names for different concentrations of their wastes e.g. typical Dairy industry terminology considers anything less than 5% suspended solids to be a liquid and 5-15% solids to be a slurry, whereas for piggeries a slurry is 10-20% solids and the wastewater industry considers anything with more than a few hundred mg/L of suspended solids to be a sludge. This *Guide* relates to all organic products with applicable concentration limits and mass loading applications to productive land, regardless of whether it is called effluent, sludge, slurry or solid.

1.1.2 EXCLUSIONS

The *Guide* does not apply to home products for self-use, nor does it apply to liquid seaweed products, non-organic mulches, non-organic soils or soil conditioners and non-compostable materials e.g. plastics. However management principles within the guide may be usefully adapted to the home environment.

Farm Dairy Effluent (FDE) is not covered by this *Guide*. The responsible management of FDE is well understood, its discharge is regulated by regional councils under the Resource Management Act and, in addition, there are a number of good management practice guidelines available from the Dairy NZ website (<http://www.dairynz.co.nz/>).

Only healthy animal wastes can be recycled. If there is an incidence of disease outbreak then recycling of associated material must stop and the facility controlled in accordance with the Biosecurity Act.

Irrigation of dilute effluents with concentrations below those in this *Guide* is also excluded.

1.2 SOIL REPLACEMENT REQUIREMENTS

The *Guide* does not provide a specification for replacement soil:

- For the urban, commercial, industrial and rural residential areas refer the Ministry for the Environment National Environmental Standard for Assessing and Managing Contaminants in Soil to Protect Human Health, April 2012, publication reference number: ME1092. Refer <http://www.mfe.govt.nz/publications/>
- For rural non-residential areas (agricultural land) refer Envirolink Tools Grant: C09X1402. Refer <http://www.envirolink.govt.nz/envirolink-tools/>. Which developed selective soil guideline values developed to protect terrestrial biota (Eco-SGVs).

However this *Guide* recommends the following protocols for the situation where organic products are used as a complete soil replacement:

- **In the rural environment;** the product should meet the *Guide* product concentration limits and the nitrogen application limits based on the land type i.e. 'ordinary' or degraded. The soil concentrations should be measured before and after to ensure that the Eco-SGV limits are maintained, except for contaminated land where the resultant soil values could be higher.
- **In the urban environment;** the product concentration should meet the Eco-SQV concentrations except for Zn. Data shows that green waste and food waste Zn concentrations are around 300ppm. The Eco-SQV limit for Zn is 190ppm. This would limit the application of home compost being applied to home gardens. The 300ppm comes from the soil limits in the 2003 Biosolids Guidelines which is considered more appropriate. Data suggests there will be no issue with the other metal limits in the Eco-SQVs.

Currently there are no Eco-SGV soil limits for Hg or Ni and the soil limits of 1ppm Hg and 60ppm Ni in the Guidelines for the Safe Application of Biosolids to Land in New Zealand, 2003 should be used (refer Volume 1, Table 9.2).

1.3 THE GUIDE

The *Guide* comprises two volumes:

- Volume 1 *Guide*, which provides guidance on how to safely use organic materials and derived organic products and discusses management issues and the recommended grading and management framework; and
- Volume 2 Technical Manual (this document), which provides detailed supporting information about how the limit values were decided, the current regulatory framework, how to implement some of the recommendations in the *Guide* and selected technical information from Volume 2 of the 2003 New Zealand Biosolids Guidelines for historical reference.

Some information in Volume 1 *Guide* has been taken directly from the 2003 Biosolids Guidelines and therefore is not repeated within Volume 2 Technical Manual (this document).

The *Guide* supersedes Guidelines for the Safe Application of Biosolids to Land in New Zealand, 2003 and its reference in NZS 4454:2005, Composts, Soil conditioners and Mulches. Useful background material from the guidelines, plus recent research reports and advice have been retained for reference within this companion Technical Manual.

The change in scope of the *Guide* from the 2003 NZ Biosolids Guidelines recognises that all wastes of animal origin, whether human or otherwise, contain similar levels of pathogens, trace elements and organic contaminants and therefore pose similar risks to productive soils and society. We should manage those risks in a similar manner.

A fundamental premise of the *Guide* is that a wide range of organic material can be beneficially recycled to land, providing that both the process of product manufacture and the process of applying the material to land are subject to adequate management control, and providing the organic material is applied at a rate that does not exceed the agronomic nitrogen requirements of crops.

The *Guide* provides both rules and practical guidance to ensure that these benefits can be realised.

These documents comprise a Guide rather than a Standard since it is not part of statute law and compliance is therefore not mandatory. Other titles were considered but Guide is consistent with its predecessors and national guidance is what it provides. Given the demonstrated central and local government and extensive industry support, it is expected that all New Zealand councils will use this guidance consistently and integrate the good practice into their district and regional plans and resource consents with industry acceptance and support. It will therefore become national good practice.

The *Guide* is intended to be a 'living document'. It is based on current knowledge about the use of organic matter in New Zealand and overseas, and will be regularly reviewed in the light of future research findings and management experiences.

Reviews are intended to be undertaken by representatives of the current Steering Group organisations, led by Water New Zealand on a 5 yearly basis. Selective updates based on the latest science may be issued without prior consultation.

1.4 OVERVIEW OF GUIDE REQUIREMENTS

This *Guide* covers the beneficial application of a wide range of organic materials to productive land. In summary the key issues are:

- The organic materials themselves, or the products derived from them, are classified according to their stabilisation and contaminant grades as follows:

Table 1-1 Product types

Type	Stabilisation Grade	Contaminant Grade
A1	A	Compliant
B1	B	Compliant
A2	A	Non-compliant
B2	B	Non-compliant

Grade A is considered essentially pathogen free and Grade B contains pathogens as noted in Table 1-2 below.

Table 1-2 Product Pathogen Standards

Pathogen	Standard
Verification Sampling:	
<i>E. coli</i>	less than 100 MPN/g
<i>Campylobacter</i>	less than 1/25g
<i>Salmonella</i>	less than <2 MPN/g
<i>human adenovirus</i>	less than 1 PFU/0.25g
<i>helminth ova</i>	less than 1/4g
Routine Sampling:	
<i>E. coli</i>	less than 100 MPN/g

Table 1-3 summarises the product contaminant concentration limits. Products that contain any contaminant at a concentration greater than the specified limit are non-compliant.

Table 1-3 Product Contaminant Concentration limits

Parameter	Concentration limit (mg/kg dry weight)
Metals:	
Arsenic	30
Cadmium	10
Chromium	1500
Copper	1250
Lead	300
Mercury	7.5
Nickel	135
Zinc	1500
Emerging Organic Contaminants (EOCs):	
Nonyl phenol and ethoxylates (NP/NPE) ⁴	50
Phthalate (DEHP)	100
Linear alkyd benzene sulphonates (LAS) ⁵	2600

Musks – Tonalide	15
Musks – Galaxolid	50

- ◆ Nitrogen loading is the primary limit on product application to land and is supported by product concentration limits and soil Eco-SGVs should soil replacement occur:
 - ~ For the continual application of organic materials on productive land the nitrogen application rate should not exceed an average of 200 Kg total N/Ha/year over up to two years, based on evidence that the organic nitrogen present in the product is eventually mineralised. Additional applications should be based on a location specific site and crop assessment.
 - ~ Organic materials application to rebuild degraded soil or to refurbish contaminated land should be limited to a one-off nitrogen application of 150 kg mineral N/Ha. For most product applications this will be greater than that for productive land.
- ◆ Given that nitrogen loading is the primary means of limiting the amount of contaminants applied to land, there need not (theoretically) be a maximum contaminant concentration. However, a maximum contaminant concentration is required for management controls and to reinforce the differentiation between a quality organic product and an unknown or non-compliant waste material.

The following sections provide background technical information explaining and in support of these pathogens, contaminants and the use of nitrogen as a primary land application control to safeguard our soils.

2 EXCERPTS FROM 2003 NZ BIOSOLIDS TECHNICAL MANUAL

This section contains excerpts from the 2003 New Zealand Biosolids Guidelines for historical record. Topics include:

- Sources of Contaminants
- Risks
- Soil Characteristics
- Contaminant Limits
- Product Stabilisation
- Monitoring and Quality Assurance
- Sampling

This section contains excerpts from the 2003 New Zealand Biosolids Guidelines for historical record. While it refers almost exclusively to biosolids, much of the advice on contaminant transfer mechanisms and management controls can equally be applied to other similar organic material such as manures. All agricultural wastes have the potential to contain pathogens and contaminants. As it is a record from the 2003 Biosolids Guidelines there has been no update to the terminology or references contained in section 2, some of which will have since been updated.

In the following sections *Guidelines* refers to the 2003 NZ Biosolids Guidelines.

2.1 SOURCES OF CONTAMINANTS IN SLUDGE

A large range of contaminants are discharged to sewer. These are transferred during the processes of sewage treatment into sludge, which forms the base ingredient for biosolids. Sewage treatment destroys few of these contaminants, merely transferring them from the liquid to the solid phase. To improve waste management practices, an important aim must be to reduce inputs of contaminants entering the wastewater system in the first instance.

This section is largely based on a report for the European Commission, *Pollutants in Urban Wastewater and Sewage Sludge* (IC Consultants, 2001), which provides background information on the sources of contaminants in sewage sludge. There have been no comparable New Zealand studies published.

2.1.1 METALS AND CONTAMINANTS

The majority of metals in raw sewage are transferred to sewage sludge during treatment (see Figure 2-1, Source: ADEME, 1995.). However, significant quantities may be lost in the treated effluent depending on the solubility of the metal concerned.

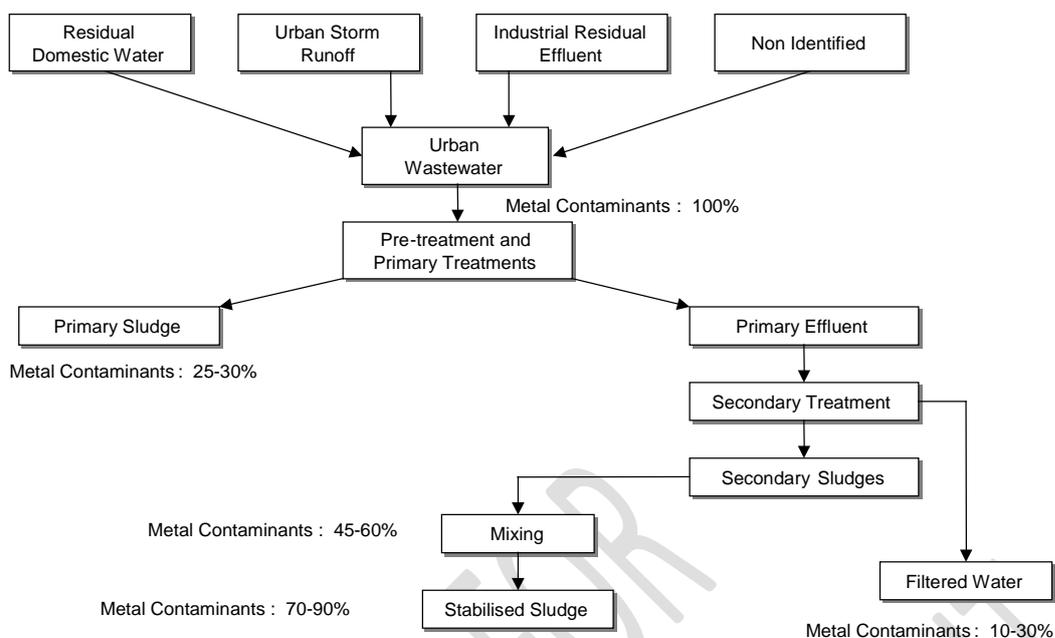


Figure 2-1 Origin and fate of metals during treatment of wastewater

Average concentrations of metals in German domestic and commercial wastewater are given in Table 2-1. The maximum concentrations found in commercial wastewater are generally greater than those in domestic wastewater.

Typically, the origin of up to 50% of the metals present in wastewater cannot be accounted for. Better source inventory data are therefore essential in order to effectively target reductions in emissions from all the different sources. Identifying some of the industrial sources may require increased trade effluent discharge controls, while domestic and urban run-off sources may require different types of action, such as changes in the use of products containing these metals

Table 2-1: Concentrations of metals in domestic and commercial wastewater

Metal	Domestic wastewater (g/m ³)	Commercial wastewater (g/m ³)
Lead	0.1	13
Copper	0.2	0.04–26
Zinc	0.1–1.0	0.03–133
Cadmium	< 0.03	0.003–1.3
Chromium	0.03	20
Nickel	0.04	7.3

Source: Wilderer and Kolb, 1997.

Emissions of contaminants from industrial point sources used to be the major source of pollution to urban wastewater for most industrialised countries in the northern hemisphere. However, stringent and more widespread tradewaste limits applied to these larger industries have considerably

reduced the levels of metals that they discharge into urban wastewater. In many countries there has been a general decline of metals discharged from industrial sources since the 1960s, due to factors such as cleaner industrial processes, trade effluent controls and heavy industry recession.

2.1.1.1 DOMESTIC SOURCES OF METALS

Domestic sources of metals in wastewater are rarely quantified because of the difficulty in isolating them from other waste streams. Domestic sources include those metals discharged from the household, as well as corrosion from materials used in distribution and plumbing networks, tap water and detergents. A study by the RIVM (Dutch Institute of Public Health and the Environment) in the Netherlands (Speed, 1993) quantified the waterborne emissions of metals from household sources, dentistry and utility buildings in the urban environment. Table 2-2 shows this data in tonnes per annum.

Table 2-2 Emissions of metals from urban sources in the Netherlands

Metal	Gross waterborne emissions to surface water in 1993 (tonnes/year)		
	Household sources	Dentistry	Utility buildings
Copper	94	0.6	27
Zinc	118	-	26
Lead	13	-	3.1
Cadmium	0.7	-	0.2
Nickel	7.3	-	0.9
Chromium	2.9	-	0.3
Mercury	0.3	2.3	0.01

Source: Adapted from Speed, 1993.

Domestic products containing metals used on a regular basis at home and/or at work were reviewed by Lewis (1999). The main domestic sources of metals in wastewater were estimated by WRc (1994) to be (in order of importance):

Cadmium: faeces > bath water > laundry > tap water > kitchen

Chromium: laundry > kitchen > faeces > bath water > tap water

Copper: faeces > plumbing > tap water > laundry > kitchen

Lead: plumbing > bath water > tap water > laundry > faeces > kitchen

Nickel: faeces > bath water > laundry > tap water > kitchen

Zinc: faeces > plumbing > tap water > laundry > kitchen.

The following lists the principal metals and the products containing them that can enter urban wastewater.

- ◆ **Cadmium**

This is predominantly found in domestic rechargeable batteries (nickel–cadmium batteries), in paints and in photographic chemicals. The main sources in urban wastewater are food products, detergents and bodycare products, and stormwater (Ulmgren, 2000a,b).

- ◆ **Copper**

This comes mainly from corrosion and leaching of plumbing, fungicides (cuprous chloride), pigments, wood preservatives, larvicides (copper acetoarsenite) and anti-fouling paints.

- ◆ **Mercury**

Most mercury compounds and uses are now (or about to be) banned, although elemental mercury is still used in thermometers and dental amalgam. Mercury can still also be found as an additive in old paints for waterproofing and marine anti-fouling, in old pesticides (including fungicides and insecticides), in wood preservatives, in embalming fluids, in germicidal soaps and antibacterial products, as mercury-silver-tin alloys, and in ‘silver mirrors’.

- ◆ **Nickel**

This element can be found in alloys used in food processing and sanitary installations, in rechargeable batteries (nickel–cadmium), and in protective coatings.

- ◆ **Lead**

The main source of lead in Europe is from old lead piping in the water distribution systems. This may also be true for New Zealand. It can also be found in old paint pigments (as oxides, carbonates), solder, pool cue chalk (as carbonate), in certain cosmetics, in glazes on ceramic dishes and porcelain (although this use is now banned), and in ‘crystal glass’. Lead has also been found in wines, possibly from the lead-tin capsules used on bottles and from old wine-processing installations.

- ◆ **Zinc**

This comes from corrosion and leaching of plumbing, water-proofing products, anti-pest products (including insecticides and fungicides, rat poison, rabbit and deer repellents, and anti-moth agents), wood preservatives, deodorants and cosmetics, medicines and ointments, paints and pigments, printing inks and artist’s paints, a colouring agent in various formulations, a UV absorbent agent in various formulations, and ‘health supplements’.

- ◆ **Arsenic**

Arsenic is one of the most toxic metals found in urban wastewaters, and is important because of its ability to cause deleterious effects on human/animal health. Arsenic come from natural background sources and from household uses such as washing products, medicines, garden products, wood preservatives, old paints and pigments. It is present mainly in urban effluents and sewage sludge as dimethylarsinic acid and as As (III) (arsenite) (Carbonell-Barrachina et al., 2000).

2.1.1.2 THE CONTRIBUTION OF HOUSEHOLD PRODUCTS

Several studies have investigated household products as sources of metals entering the sewer (Comber and Gunn, 1996; WRc report, 1994).

There can be a great deal of variability in metal content between products and between types of the same product. The high variability of cadmium concentrations found in big-box washing powders,

for example, can be explained by the differences in the composition of phosphate ores used in their production. Reducing the amount of phosphate in washing powders, or choosing phosphate ores with low cadmium concentration, could lead to a reduction in cadmium in wastewater from diffuse sources. In Sweden the amount of cadmium in sewage sludge was reduced from 2 mg/kg dry solids to 0.75 mg/kg dry solids (Ulmgren, 1999), and cadmium discharges from households in the Netherlands have been substantially reduced due to the switch to phosphate-free detergents (Speed, 1993). The 'ultra' washing powders, usually phosphate-free, have lower amounts of toxic metals than the traditional powders, and are designed to be used in smaller quantities. A shift to these newer products will reduce the overall metal load from this source.

The products with the highest metal contents include medicated (e.g., anti-dandruff) shampoos, which contain zinc pyrithione. Cosmetics may also contain high levels of zinc, and several of these products will enter the wastewater system. One study in France (ADEME, 1995a) identified the main sources of metals in domestic wastewater as cosmetic products, medicines, cleaning products and liquid wastes (including paint), which were directly discharged from the household sink.

2.1.1.3 DOMESTIC WATER AND HEATING SYSTEMS

Studies in the US (Isaac et al., 1997), and Europe (WRc, 1994) show that corrosion of the distribution/plumbing/heating networks contribute major inputs of lead, copper and zinc. Lead concentrations, for instance, can vary between 14 µg/L at the household input and 150 µg/L at the output. It has been found that concentrations of copper in sewage sludge are directly proportional to water hardness (Comber and Gunn, 1996). Hard water (high pH) is potentially more aggressive to copper and zinc plumbing, increasing leaching. However, the opposite is true for lead, which dissolves more readily in soft, acidic water.

The addition of alkaline agents to water at the treatment stage and the replacement of much lead piping has led to reductions in lead concentrations (Comber and Gunn, 1996). Zinc in domestic plumbing comes from galvanised iron used in hot water tanks, but is less problematic than lead and copper because the amount actually decreases with the ageing of the installations. Copper corrosion and dissolution are also greater in hot water than in cold water supplies (Comber and Gunn, 1996). The 'first draw' (i.e. initial flow of water in the morning) has higher amounts of copper and lead compared to subsequent draws (Isaac et al., 1997).

2.1.1.4 *The influence of various treatment processes on the fate of metals and their* TRANSFER TO SEWAGE SLUDGE

The idea of treating wastewater (sewage) is to remove the various solids and contaminants so as to end up with water that is suitable for discharge to the environment. The material removed is sludge, which, if suitably treated, can become biosolids. This raises the issue that the very nature of the removal process acts to concentrate contaminants, including trace metals. It turns out that the degree of concentration varies according to the type of treatment and the type of metal.

Sludges from conventional sewage treatment plants are derived from primary, secondary and tertiary treatment processes. The contaminant load in the raw wastewater is transferred to the sludge as settled solids at the primary stage, and as settled biological sludge at the secondary stage. Contaminants are also removed along with the solids during the primary and secondary sedimentation stages of conventional wastewater treatment. Metal removal during primary sedimentation is a physical process, dependent on the settlement of precipitated insoluble metals, or the association of metals with settleable particulate matter. Little removal of dissolved metals occurs at this stage, and the proportion of dissolved metal to total metal in the effluent increases as a result.

Just how efficiently the suspended solids are removed is the main factor influencing the extent of metal removal during primary wastewater treatment. However, the relative solubilities of different metals present in the wastewater are also important. Thus, nickel shows the poorest removal (24 %)

during primary treatment, whereas 40% of the cadmium and chromium in raw influent is transferred to the primary sludge, and more than 50% of the zinc, lead and copper.

The removal of metals during secondary wastewater treatment is dependent on the uptake of metals by the microbial biomass, and the separation of the biomass during secondary sedimentation. Several mechanisms are important here, including physical trapping of precipitated metals in the sludge floc, and binding of soluble metal to bacterial extracellular polymers. The patterns of metal removal from settled sewage by secondary treatment are similar to those recorded for primary sedimentation. However, general surveys of removal efficiencies suggest that secondary treatment (by the activated sludge process) is more efficient at removing certain metals (e.g. chromium) than the primary stage.

Operational experience and metal removal measured by experimental pilot plant systems can indicate the overall likely transfer to sludge of toxic metals from raw sewage during conventional primary and secondary wastewater treatment. This shows that approximately 70–75% of the zinc, copper, cadmium, chromium, mercury and arsenic in raw sewage is removed and transferred to the sludge (Blake, 1979), and concentrations of these metals in the final effluent would be expected to decrease by a similar amount compared with the influent to the water treatment plant. Up to 80% of lead may be removed, whereas the smallest overall reductions are obtained for nickel, approximately 40% of which may be transferred to the sludge.

Most of the metals in raw sewage are partitioned during wastewater treatment into the sewage sludge or the treated effluent. However, atmospheric volatilisation of mercury as methylmercury, formed by aerobic methylation biotransformation processes, is also suggested as a possible mechanism contributing to the removal of this element during secondary wastewater treatment by the activated sludge system (Yamada et al., 1959). However, although some of the mercury removal observed in activated sludge may be attributed to bacterially mediated volatilisation, it is unlikely that this is a major route of mercury loss because of the significant quantities of this metal recovered in surplus activated sludge (Lester, 1981).

2.1.1.5 THE NEW ZEALAND CONTEXT

There have been no New Zealand studies comparable to those summarised above. Similar findings would, however, be expected to emerge from any such studies due to similarities in the lifestyles and consumer products used in this country, although New Zealand water supplies tend to be more aggressive (corrosive) than many European waters and this may increase the tendency for metal dissolution into the wastewater stream and thereby into sewage sludge.

2.2 RISK ASSESSMENT

2.2.1 INTRODUCTION

This risk assessment of biosolids is not based on strict quantitative risk because there are insufficient data available for New Zealand. It is estimated (NRMMC, 2003) that at least 10 years' research is required before such an analysis is possible. A qualitative analysis has therefore been used, having regard to the precautionary principle.

The risks associated with the beneficial use of biosolids are described in the following sections.

2.2.2 RISKS TO PLANT HEALTH

Biosolids are applied to plants because the nutrients and trace metals they contain are usually beneficial to crop growth and health. However, some metals present in biosolids are only beneficial to plant health/growth at particular concentrations, and beyond that level may be detrimental to the plant. Copper, nickel and zinc are the main metals that can have toxic effects on plants. The limits

set for biosolids in these *Guidelines* are designed to ensure that the concentrations of these metals in soils after the application of biosolids do not have any phytotoxic effect on any plants present.

Cadmium, while not apparently phytotoxic, can accumulate in plant tissues to such an extent that it becomes toxic to humans and/or grazing animals. The levels given for cadmium in these *Guidelines* are designed to prevent this from occurring.

Arsenic, mercury, chromium (in the form of chromate [VI]) and lead may also be toxic to plants. However, the majority of plants do not take these metals up easily and so are only likely to be affected by the presence of these metals at high concentrations. Once again, the limits given in these *Guidelines* are designed to prevent this from happening.

The pH of the soil can affect the mobility of certain metals, with mobility increasing as the soil becomes more acid. In Europe, several countries (UK, Spain and Portugal) have tried to address this bio-availability issue by giving different soil limits for soils of different pH. The mechanisms behind bio-availability are not well understood and it is felt that more research needs to be undertaken before this type of approach is used in New Zealand. These *Guidelines* assume 100% bio-availability of all metals, which is extremely unlikely and therefore represents a margin of safety built into the recommended limits.

There is no evidence to suggest that plant diseases are transmitted in sewage sludge or biosolids (Smith, 1996).

2.2.3 RISKS TO ANIMAL HEALTH

Animals may be exposed to biosolids if they are used as a fertiliser on paddocks and pastures. Animal fodder may also be grown in fields treated with biosolids. However, the main risk to animal health is the direct ingestion of biosolids by livestock when grazing on treated pasture.

Cadmium, mercury and copper are particularly toxic to animals if ingested, and there is some concern that animals grazing on biosolids-treated grass could be affected by these metals (DEFRA, 1998). However, the likelihood of toxic effects occurring if animals are fed food that has been treated with biosolids, rather than ingesting the biosolids themselves, is thought to be low (Wellington City Council, 1997).

Concern has also been raised regarding the accumulation of some organic compounds in the tissues and milk of grazing animals. While there is no evidence that this type of accumulation is detrimental to the animal (Smith, 1996), it may be harmful to humans who eat the meat and drink the milk of animals who have accumulated these organic compounds.

2.2.4 RISKS TO SOIL MICROBIAL PROCESSES

There is much debate over the effect of metals present in biosolids on soil micro-organisms and microbial activity, and much of the available literature is contradictory. This is because the toxicity of metals is dependent on many factors, including soil pH, the tolerance of soil micro-organisms to the metal being investigated, the presence of other metals and the soil type. The debate is further complicated by the interactions that can occur between some of these factors.

Initial concern regarding soil microbial processes was raised after an experiment conducted at Woburn in the UK in 1984 indicated that nitrogen-fixing bacteria were adversely affected by the application of sludge to the soil. However, subsequent studies have shown little or no effect.

2.2.5 RISKS TO HUMAN HEALTH

Risks to humans can come both from direct exposure to biosolids and from eating food that has been grown on land to which biosolids have been applied. The risks posed to humans can be divided into three categories: pathogens, metals and organics. These are discussed in turn below.

2.2.5.1 PATHOGENS

All sludges that are used to produce biosolids will contain pathogens in varying numbers. The number of pathogens in the final product will depend on the treatment used to produce the biosolids. The methods used to apply the sludge to land can further decrease the risk to humans by affecting the rate of die-off, reducing the numbers present and/or decreasing the likelihood of human contact.

Pathogen numbers can be reduced directly or indirectly by:

- ◆ Sunlight;
- ◆ ambient temperature;
- ◆ desiccation;
- ◆ soil pH;
- ◆ soil characteristics;
- ◆ presence of competing organisms; and
- ◆ quantity of sludge spread.

Irrespective of the numbers or type of pathogens present in the final product, the application of biosolids to the surface of the land is more effective at reducing pathogen numbers than incorporating the product into the soil, due to the effects of sunlight, air temperature, etc. However, although it may not reduce pathogen numbers to the same extent, incorporating biosolids into the soil has the effect of reducing the probability of human contact, so in terms of reducing the risk to human health it can be as (or more) effective than surface application. For this reason and others soil incorporation is preferred for all biosolids applications.

Workers involved in the production of and/or application of biosolids are particularly at risk from exposure to pathogens and should follow the appropriate safety procedures.

2.2.5.2 METALS

The US National Research Council (1996) has reported that no adverse human acute or chronic toxic effects have been reported as the result of ingesting foods grown in soils amended by sludges and/or biosolids. This is probably because any plants that contain metals at a level harmful to humans would be so damaged themselves they would be unsuitable for sale.

In terms of human exposure, the main metals of concern are cadmium, lead and mercury. Direct ingestion is considered to be the most critical pathway for these metals, and this is based on children playing in domestic gardens to which biosolids have been applied (USEPA, 1995). Even though the USEPA approach (USEPA, 1993) is based on conservative assumptions, the biosolids limits given for metals in the US standard are often much higher than those set in Europe and in Australia.

2.2.5.3 ORGANIC COMPOUNDS

The risk to humans from exposure to organic compounds found in biosolids is thought to be minimal. However, some organic compounds, including the PCBs and persistent organochlorine pesticides, have been found to accumulate in the meat and milk of livestock, and these may therefore be passed on to human consumers of animal products.

It should also be noted that, historically, some wood treatments used pentachlorophenol (which is contaminated with dioxins) and other organochlorine pesticides, so sawdust and wood chips used as a co-product in the composting process must come from non-treated wood.¹

¹ This requirement will also prevent biosolids being contaminated with copper, chromium and arsenic from CCA treated timber.

2.2.5.4 RISK TO GROUNDWATER AND SURFACE WATER

The leaching of nutrients such as nitrogen and (to a certain extent) phosphorus is the main risk posed to groundwater by the application of biosolids. Limiting application rates by linking them to the agronomic rate of nitrogen uptake should help to resolve this issue. Nitrogen leaching can also be reduced by applying biosolids at or as close to the time when maximum crop growth and nitrogen uptake occur. Compared to nitrogen, phosphorus is relatively immobile in soils and will not leach at the same rate.

Metals are unlikely to move through the soil and into groundwater because of the binding mechanisms in soil. However, some movement may occur through acidic, sandy soils under conditions of high biosolids application, coupled with either irrigation or high rainfall.

The organic contaminants covered by the 2003 Biosolids Guidelines are unlikely to move from biosolids to groundwater because of their low water solubility and the binding properties of the soil.

Risks to surface water are similar to those discussed above for groundwater. They can be reduced by ensuring that biosolids are not spread too close to watercourses, on waterlogged or steeply sloping land or during periods of heavy rainfall.

2.2.5.5 RISKS TO AIR QUALITY

The main risk to air quality from the application of biosolids is odour. This can be controlled by ensuring that the biosolids are incorporated into the soil within a few hours of application. Incorporation of biosolids will also reduce ammonia emissions, and therefore the amount of nitrogen lost to the atmosphere.

2.3 SOIL CHARACTERISTICS AND INTERACTION WITH BIOSOLIDS CONTAMINANTS

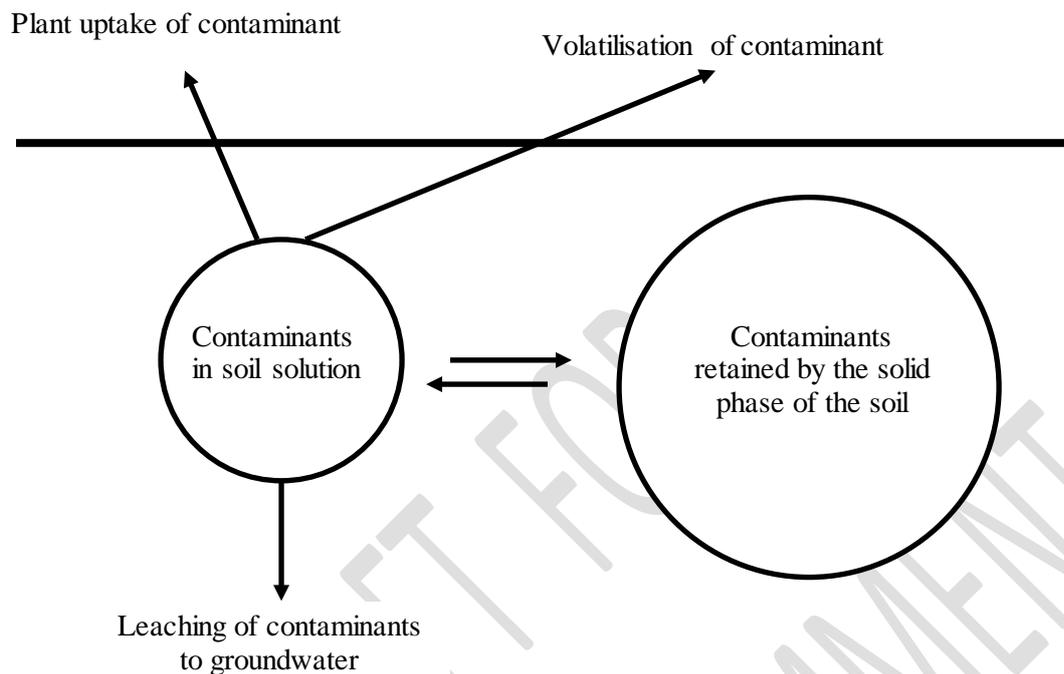
2.3.1 INTRODUCTION

The interaction and fate of contaminants in biosolids applied to the soil are fundamental to the short- and long-term effects of biosolids use. This chapter summarises the behaviour of contaminants in soil in sufficient detail to enable the user to understand the issues and complexities. It also discusses the effects of land management practices on contaminant uptake and mobility.

Contaminants can be involved in many different reactions and processes in the soil, but their ultimate fate can be summarised as shown in Figure 2-2. Essentially, contaminants can:

- ♦ react with and become retained by the solid phase of the soil;
- ♦ be volatilised into the atmosphere as a result of various physical, chemical and biological transformations;
- ♦ be taken up by plants;
- ♦ be leached out of the soil into drainage water;
- ♦ be removed in soil ingested by grazing animals and
- ♦ be transported to another location in surface runoff.

Figure 2-2 Simplified depiction of the fate of contaminants in the soil



Not every contaminant is subject to all of the above processes, and in some cases a single process may dominate the fate and potential adverse effects of a contaminant. For example, most metals are not subject to volatilisation losses, and the fate of nitrogen is often dominated by leaching from the soil.

2.3.2 RETENTION PROCESSES

Contaminants entering the soil, whether metals or organic compounds, are subject to numerous chemical and biological processes that have implications for contaminant bio-availability and mobility. Some of the most important processes are those responsible for the accumulation of contaminants in the solid-phase components of the soil, processes collectively referred to as 'contaminant retention'. Metals or organic chemicals retained by the soil are generally considered to be less bio-available and mobile than those remaining in the soil solution.

2.3.2.1 METAL RETENTION

2.3.2.1.1 EXCHANGEABLE METALS

Metals that occur as cationic species might be expected to take part in normal cation exchange mechanisms in the soil (i.e., non-specific, electrostatic attraction of cations to negatively charged soil colloids). Similarly, metals that occur in anionic forms may interact with anion exchange sites. However, it seems unlikely that ion exchange is a particularly important mechanism for the metallic elements (Swift and McLaren, 1991; Barrow, 1999). The concentrations of major nutrient ions (e.g., Ca^{2+} , Mg^{2+} , K^+ , NO_3^- , SO_4^{2-}) in the soil solution are several orders of magnitude greater than those of the metals. Thus, mass action (competition) effects should prevent the occurrence of significant concentrations of metals on exchange sites, except in grossly contaminated soils. This is confirmed by the observation that only extremely small concentrations of exchangeable metals are determined in soils using standard techniques of extraction; i.e., extraction with salt solutions (Tiller et al., 1972; McLaren and Crawford, 1973a; Shuman, 1979).

2.3.2.1.2 METALS SPECIFICALLY SORBED BY INORGANIC SOIL COLLOIDS

The sorption of trace metals by inorganic soil colloids such as aluminosilicate clays and iron, aluminium and manganese oxides and hydroxides are considered to occur mainly by specific sorption mechanisms (Swift and McLaren, 1991). This means that the soil colloid shows a preference for the sorbed substance, so that metal ions such as Cu^{2+} or Zn^{2+} may be sorbed despite the presence of much higher concentrations of Ca^{2+} or Mg^{2+} (Barrow, 1999). Unlike the mechanism of ion exchange that involves electrostatic bonding only, specific sorption involves the formation of a stable chemical bond between a trace element ion and certain functional groups at the surface of the soil colloid. Evidence for the formation of these bonds has been obtained by both indirect and direct methods (McBride, 1989). However, it should be appreciated that as a result of the large number of chemical species, surfaces and bonding mechanisms involved, specific sorption processes in soil are extremely complex.

2.3.2.1.3 METALS COMPLEXED OR CHELATED BY ORGANIC COLLOIDS

As with inorganic colloids, soil organic colloids are able to bind substantial concentrations of metals, and with some metals (e.g., copper) the bonds formed are very strong. It is generally assumed that bonding is the result of complex formation involving the various functional groups (carboxyl, hydroxyl, etc.) found in soil organic matter in general, and humic substances in particular (Stevenson, 1982). Where ring structures are formed by this type of reaction, the element is said to be chelated. The complexation of trace metals by organic colloids can also be regarded as an example of a specific sorption mechanism.

2.3.2.1.4 METALS OCCLUDED BY, OR AS STRUCTURAL COMPONENTS OF, SECONDARY MINERALS AND OTHER INORGANIC COMPOUNDS

Trace elements sorbed on to the surfaces of iron, aluminium and manganese oxides may eventually be occluded by further growth of the oxides. Alternatively, metals may be substituted in the structures of oxide minerals during their formation in soils. For example, there is good evidence for the substitution of trace metals in the structures of a range of iron oxides and oxyhydroxides (Gilkes and McKenzie, 1988; Cornell and Schwertmann, 1996). In some cases it may also be possible that metals are precipitated in the form of simple inorganic compounds such as carbonates, phosphates, sulphides or hydroxides. However, this is most likely to happen only in heavily contaminated soils, under waterlogged or high pH conditions, or in calcareous soils. For most soils there is little evidence for the existence of such compounds (Swift and McLaren, 1991).

2.3.2.2 FACTORS AFFECTING METAL RETENTION

2.3.2.2.1 SOIL COMPOSITION

Since metals are retained predominantly by soil organic matter, soil oxides and clay minerals, those soils with high contents of these constituents will have a larger capacity to retain metals. Conversely, soils with low organic matter, low oxide and low clay contents are likely to have a limited ability to retain metals.

2.3.2.2.2 SOIL PH

Numerous studies have examined the effect of pH on metal retention processes. In general it has been observed that pH has a profound effect on metal retention behaviour by all major soil constituents (Swift and McLaren, 1991). For example, metal retention by soil organic matter increases substantially from pH 2 to 6 (Kerndorff and Schnitzer, 1980; McLaren and Crawford, 1973b; McLaren et al., 1986). Similarly, for those metals occurring as cations, retention by inorganic soil constituents (oxides and clay minerals) also increases with an increase in soil pH.

For metals or metalloids occurring as anions, the picture is more complex (e.g., molybdenum, selenium and arsenic). In some cases, retention of these metals decreases with an increase in pH (e.g., Hingston et al., 1972), and in other cases retention increases to a maximum and then decreases with a further increase in pH (e.g., Smith et al., 1999). The exact nature of the pH effect in these cases will be determined by factors such as the types of soil constituent involved and the presence of co- or competing ions.

2.3.2.2.3 SOIL REDOX CONDITIONS

Redox (reduction–oxidation) conditions affect metal retention in two main ways. Firstly, under waterlogged, anaerobic conditions oxides of iron and manganese become reduced and are solubilised, releasing any bound metals back into solution. Secondly, a small group of metals or metalloids (arsenic, selenium and mercury) are capable of being volatilised from the soil under reducing conditions.

2.3.3 CONTAMINANT VOLATILIZATION

Under anaerobic conditions, both bacteria and fungi have the ability to transform arsenic into volatile forms, predominantly dimethylarsine and trimethylarsine gases (Tamaki and Frankenberger, 1992). Similarly, selenium volatilisation from soils can occur as a result of microbial methylation reactions (Haygarth, 1994). Numerous bacteria and fungi appear to be responsible for this process, and the main volatile species produced is the non-toxic dimethylselenide (Frankenberger and Losi, 1995).

Mercury, like arsenic and selenium, can also undergo microbial methylation reactions in the soil to produce methyl mercury species (Kabatas-Pendias and Pendias, 2001). Another naturally occurring process is microbial reduction of mercuric ions (Hg^{2+}) to elemental mercury (Hg^0), which can then be volatilised from the soil. There is good evidence that Hg can be volatilised from soils contaminated with a variety of mercury-containing materials, including municipal sewage sludge (Carpi and Lindberg, 1997).

Some organic compounds (e.g. some pesticides) will also volatilise, a process determined predominantly by the solubility and vapour pressure of the particular compound. In addition, all organic molecules will undergo some biological and/or chemical decomposition or transformation in the soil. For those organic compounds that are easily decomposed, their retention in the soil will not be a major issue. However, for the persistent pesticides, PCBs and dioxins that are addressed by these *Guidelines*, they decompose only extremely slowly, and as they are not lost by volatilisation or leaching to any significant extent, they will be retained in the soil for considerable periods of time (years to decades).

The nitrogen added in biosolids can also be lost from the soil to the atmosphere through volatilisation as ammonia (NH_3), or by denitrification, predominantly in the form of nitrous oxide (N_2O), but also possibly as nitric oxide (NO) and nitrogen gas (N_2) (McLaren and Cameron, 1996). Some biosolids are rich in ammonium-N, and substantial volatilisation of ammonia gas may take place immediately following application to the soil, particularly under conditions of high pH and with surface applications. Denitrification is most likely to take place under wet, anaerobic conditions.

2.3.4 CONTAMINANT BIO-AVAILABILITY

2.3.4.1 METAL BIO-AVAILABILITY

To be available for uptake by plants (or soil micro-organisms), metals must be present in the soil solution. Solution metal concentrations are controlled in two main ways:

- ♦ by the solubility of solid-phase compounds containing the metal of interest;
- ♦ by sorption/desorption reactions at the surfaces of soil colloids.

Solubility of their respective oxides is probably the main factor controlling solution concentrations of aluminium, iron and manganese, but for all other trace metals sorption/desorption reactions are likely to be the major types of mechanism involved (Swift and McLaren, 1991). Those trace metals present in the crystal structures of primary and secondary silicate minerals, or occluded by oxides (unless soil conditions favour their dissolution), will clearly be unavailable for plant uptake.

To a large extent metal concentrations in the soil solution will be inversely related to the metal retention properties of the soil solid phase; that is, the greater the retention, the lower the metal concentration in solution. Thus any factor that affects metal retention (see above) will also affect metal solution concentrations (e.g., pH and soil composition).

However, other factors may also influence solution metal concentrations and hence bio-availability. For example, the role of the soil biomass, although by no means clear, is likely to be important. Only small amounts of trace metals will be present in the biomass, but the release of decaying organic materials and the continual cycling of trace metals through the soil microbial population could have a significant effect on maintaining solution metal concentrations.

2.3.4.2 CHEMICAL SPECIATION OF TRACE METALS IN THE SOIL SOLUTION

There is considerable evidence that the chemical speciation of trace metals in solution affects their availability and/or toxicity to plants (Parker et al., 1995). For example, many studies have shown a high level of correlation between plant uptake of trace metals and the activity of free, uncomplexed metal ions in solution, such as Cu^{2+} (Graham, 1981) and Cd^{2+} (Cabrera et al., 1988), rather than with total metal concentrations. Such studies have been interpreted as demonstrating that complexed forms of trace metals in solution are unavailable for plant uptake. However, other studies have suggested that this is not necessarily the case. For example, DeKock and Mitchell (1957) demonstrated increased uptake of aluminium and other trivalent metals by chelators such as EDTA and DTPA. More recently, Smolders and McLaughlin (1996) and Weggler-Beaton et al. (2000) have demonstrated that Cl-complexed Cd may also be available for plant uptake (in addition to Cd^{2+}).

The importance of complexed trace metal species for plant uptake from soils is difficult to assess at this stage. Much of the research has been carried out in solution cultures rather than in soil. Whether some complexed species are indeed taken up by plants, or whether complexation can enhance availability primarily by increasing the diffusion of trace metals to plant roots, remains to be determined.

2.3.4.3 SOIL PH

Soil pH is recognised as having a major influence on the availability of trace metals. For those trace metals that occur predominantly as cations (e.g., Cu^{2+} , Co^{2+} , Pb^{2+}), their availability to plants is highest in acid soils, and decreases as the soil pH increases. Conversely, those trace metals such as arsenic, molybdenum and selenium that occur as anions are most available in soils of high pH and least available in acid soils.

The influence of soil pH on trace metal availability is due mainly to its effect on the reactions controlling trace metal concentrations in the soil solution. Under acid conditions, sorption of trace metal cations by soil colloids is at a minimum, and thus solution concentrations are relatively high. In addition, the solubilities of iron and manganese oxides are high under low pH conditions. As the soil pH rises, the sorption of trace metals increase and the solubility of oxides decreases. The sorption of those metals that occur in anionic forms decreases with increasing soil pH, and hence solution concentrations and their availability increase.

A complicating factor with certain trace metal cations (e.g., Cu^{2+} and Pb^{2+}) is that as soil pH increases, metal solubility reaches a minimum between pH 6 and 7 and then rises again at even higher pH (e.g., McBride and Blasiak, 1979; Bruemmer et al., 1986). This is mainly due to increased solubility of

organic matter at high pH, causing the retention of trace metals in solution in the form of soluble organic complexes. However, as discussed above, the extent to which trace metals occurring as complexes will be available for plant uptake is unclear.

2.3.4.4 METAL DESORPTION

The immediate bio-availability of trace metals depends primarily on their concentration and speciation in the soil solution. However, continuing bio-availability depends on the soil's ability to release trace metals from the solid phase to replenish those removed by plant uptake. It is now generally accepted that in the medium to long term, solution concentrations of trace metals are most likely to be controlled by sorption–desorption reactions at the surfaces of soil colloids (Swift and McLaren, 1991).

Desorption of soil-retained trace metals shows a variety of trends, depending on the nature of both the surface and the trace metal being studied. These trends range from (a) complete desorption, to (b) significant desorption but with a proportion of trace metal retained, to (c) minimal desorption, with a high proportion retained by the surface. Many trace metals fall into category (c), appearing to be strongly retained by soils and showing limited reversibility of sorption (desorption).

As with sorption, desorption of trace metals from soils is affected markedly by soil pH. In particular, desorption of both native (i.e. naturally occurring) and applied trace metals has been observed to decrease with increasing soil pH (e.g., McLaren et al., 1997; Gray et al., 1998).

2.3.4.5 AGEING EFFECTS

The issue of whether the bio-availability of contaminant metals added to soils decreases with time is somewhat contentious, particularly in relation to metals added in biosolids. However, there is good evidence from laboratory studies using simple metal salts that increasing the contact time between soil and added metal can decrease the metal's subsequent ability to desorb from the soil (Barrow, 1986; Hogg et al., 1993; Gray et al., 1998). Such findings have been linked to observations that following the initial rapid sorption of metals by soil oxide materials, continuing slow reactions between the metal and the oxides take place (Benjamin and Leckie, 1981; Bruemmer et al., 1988; Backes et al., 1995). Whether such processes involve solid diffusion of metals into the lattice structure of oxides (which would be expected to be extremely slow) or diffusion of ions into very small pores and inter-particle spaces remains to be determined (McBride, 1991).

Whatever the mechanism, there is evidence to link such slow reactions with decreased availability of metals to plants. For example, Brennan et al. (1980) have reported reduced copper availability to plants with increasing contact time between added copper and the soil. Similar observations have been made by Brennan (1990) in relation to the availability of zinc to plants. More recently, Hamon et al. (1998) have produced evidence that cadmium added to soils in superphosphate fertiliser becomes less bio-available with time. These researchers estimated that cadmium was being fixed very slowly in non-bio-available forms at a rate of 1–1.5% of the total cadmium added per year. This observation is supported by the work of Gray et al. (1999), who, using a sequential fractionation technique, determined that a substantial proportion of cadmium applied to a soil in superphosphate over a 44-year period had been incorporated into a residual soil fraction. McLaren and Ritchie (1993) have made similar observations in relation to the long-term fate of copper in soil.

The evidence referred to above suggests that the bio-availability of metals, in simple forms and at relatively low levels of contamination, may well decrease significantly over time. However, with metals added in biosolids the picture is far from clear. Research in this area has been discussed in detail by Smith (1996). In summary, whereas some studies have indicated a decrease in metal bio-availability with time after biosolids application has ceased, others have not. A major complicating factor with biosolids studies is that in addition to metals, large amounts of organic matter are also added to the soil, sometimes along with substantial quantities of other inorganic materials. The effect of the decomposition of this organic matter and the presence of inorganic metal sorbents on

the long-term bio-availability of metals is probably the major issue facing sludge researchers at present.

2.3.4.6 BIO-AVAILABILITY OF ORGANIC CHEMICALS

Compared with research on metals in biosolids, comparatively little work has been done on the fate of the organic chemicals present in such material. However, O'Connor et al. (1991) carried out a detailed review of the bio-availability to plants of sludge-borne toxic organics. They concluded that the vast majority of these chemicals in sludges occur initially in sludge-amended soils at low concentrations, and are so strongly sorbed in the sludge–soil matrix as to have low bioavailabilities to plants. In addition, the large size of many organic molecules precludes their uptake by plants.

2.3.5 CONTAMINANT MOBILITY

Contaminants added to soil in biosolids can be mobilised by two main processes: surface run-off and leaching downwards through the soil profile. Surface run-off involves bulk movement of material (biosolids or a soil/biosolids mixture) and associated contaminants over the surface of the land in water that is unable to infiltrate readily into the soil. If such material finds its way into surface water bodies (e.g., streams), serious contamination of the water may result.

Leaching through the soil profile is probably more complex and difficult to control, and occurs because water moving through the soil generally transports any dissolved solutes with it. These solutes may be trace metals, organic molecules or nutrient ions such as nitrate nitrogen, all of which are added to the soil in biosolids applications. In some cases such transport can result in the pollution of groundwater.

2.3.5.1 PRINCIPLES OF SOLUTE TRANSPORT

Solute movement occurs through a combination of three main mechanisms: convection, diffusion and dispersion (McLaren and Cameron, 1996). Convective transport results from the movement of solutes with the mass flow of water in soil, and can be described by a modified form of Darcy's Law. Convective transport is often referred to as 'piston displacement', and the distance of transport per unit time depends on the average pore water velocity. In reality, the solute does not remain as a sharp band but tends to spread throughout the profile due to the processes of diffusion and hydrodynamic dispersion.

Diffusion occurs when there is an uneven distribution of solutes in a solution, causing a diffusive flux of solute from areas of high concentration to areas of lower concentration. Hydrodynamic dispersion is caused by the mechanical action of a solution flowing through soil, which tends to cause mixing and equalises the solute distribution. This process enhances the dispersive effect of diffusion and during flow it usually completely masks it.

Hydrodynamic dispersion occurs because (i) the flow velocity within a single pore is not uniform, (ii) the large variation in pore size in soil causes an extremely wide range of pore water velocities, and (iii) the tortuosity of pores results in a range of flow path lengths (McLaren and Cameron, 1996).

Solute transport is also affected by a number of other factors, including macropore effects, reactivity with and transformations in the soil, and plant uptake of solutes. Earthworm activity, root growth, freezing and thawing, and wetting and drying cycles can lead to the development of surface-connected macropores in the soil. Water flow through these pores can have two distinct effects on leaching:

- when water is applied immediately after a solute, macropore flow may lead to extensive leaching at a faster rate than normal; and
- when solutes are present within aggregate micropores they may be bypassed by the bulk of the flowing water and thus protected from leaching.

Reaction of solutes with the soil may also reduce the rate of leaching. Cations (including metals), which are adsorbed by soil surfaces, are generally less prone to leaching than non-adsorbed anions such as nitrate and sulphate. Some solutes are also involved in biological transformation processes that can either decrease (immobilisation) or increase (mineralisation) solute concentrations. Plant uptake of solutes decreases their concentration in the soil solution and therefore reduces their rate of leaching loss from the soil.

2.3.5.2 NUTRIENT LEACHING

Although the nutrient elements present in biosolids (e.g., nitrogen, sulphur, phosphorus, potassium, calcium and magnesium) are considered beneficial for plant growth, some of them can be regarded as contaminants if they leach into groundwater. The main element in this category is nitrogen, which in the form of nitrate (NO_3^-) is extremely mobile and has a high potential for leaching. Indeed, in the short term, the potential for nitrate to leach is the main limitation on the amount of biosolids that can be applied to the soil. Applying amounts of nitrogen in excess of crop requirements is likely to result in increased concentrations of potentially leachable nitrogen in the soil.

Phosphorus contamination of water is also a potential problem in relation to eutrophication, although little research has been reported on phosphate leaching from biosolids-amended soils. There is no doubt that phosphorus is likely to accumulate in soils that receive repeated applications of biosolids, and the implications of this in relation to phosphate leaching require attention. There is currently considerable concern worldwide regarding the build-up of phosphate in soils as a result of inorganic fertiliser applications, with the realisation that phosphate leaching from such soils may be environmentally significant (Haygarth and Jarvis, 2000).

2.3.5.3 LEACHING OF ORGANIC CHEMICALS

There is little data on the leaching of organic chemicals from biosolids-treated soils. However, for the organochlorine pesticides, PCBs and dioxins, their extremely low water solubility and strong binding ability with soil means they are unlikely to be measured in groundwater. However, it should be noted that some specific pesticides are known to be reasonably mobile in the soil and have the potential to contaminate groundwater.

2.3.5.4 LEACHING OF METALS

With some exceptions, trace metals tend to be sorbed relatively strongly by soils, and only small concentrations are present in the soil solution. They are therefore generally considered to be rather immobile in soils and their leaching down through the soil profile minimal (Dowdy and Volk, 1983; Ellis et al., 1983). However, evidence is accumulating that the leaching of both trace metal cations and anions does occur, and in some circumstances may result in significant movement of trace metals down the soil profile and into groundwater.

The suggestion by many researchers that no substantial long-term leaching losses of trace metals occur from surface soils contaminated by biosolids is often based on the observation that little trace metal accumulation is observed in the subsoil. For example, studies by Chang et al. (1984) and Williams et al. (1985) both showed that despite large applications of sewage sludge to soils, most trace metals did not appear to move below the depth of sludge incorporation. However, this assumption ignores the possibilities that (i) drainage leachate may move through preferential flow channels in the subsoil, thus bypassing most of the soil mass, and (ii) sorption of some trace metals in the subsoil may be minimal due to the dominance of organically complexed or colloid-associated forms.

The possibility that trace metals might be transported to lower depths in the soil through cracks and macropores has been suggested by Dowdy et al. (1991). Such a process could be conducive to significant leaching of trace metals without markedly increasing concentrations in the subsoil (Sidle and Kardos, 1977; Camobreco et al., 1996). It is interesting to note that at many sites where trace

metals have been added in sewage sludge treatments, mass balances calculated several years after application have been unable to account for all the trace metals applied (e.g., McGrath and Lane, 1989; McBride et al., 1997). It seems possible that these deficits could be explained, at least in part, by leaching.

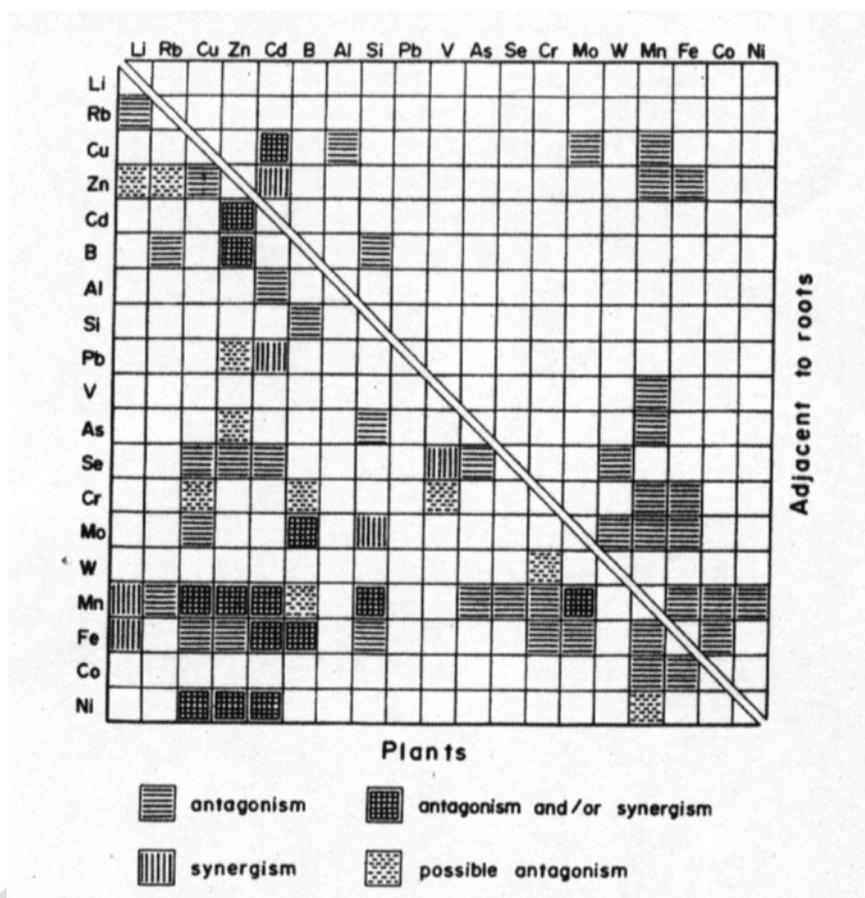
Apart from field study data, knowledge of metal movement through soils is based primarily on studies using homogenised, repacked soil columns (Camobreco et al., 1996). Such studies, even when using coarse-textured soils, have tended to support the contention that cationic trace metals are basically immobile (e.g., Giordano and Mortvedt, 1976; Gerritse et al., 1982). In recent years, however, studies using undisturbed soil columns (or lysimeters) have demonstrated the potential importance of preferential flow for trace metal leaching. For example, Camobreco et al. (1996) compared the movement of cadmium, zinc, copper and lead through undisturbed and homogenised soil columns. The homogenised columns retained all added metals, whereas substantial amounts of all four metals were present in the effluent from the undisturbed columns.

More recently, McLaren et al. (1999) have demonstrated increased metal leaching from undisturbed soil lysimeters treated with metal-spiked sewage sludge. In this study there were clear examples of the preferential flow of metals taking place, with increased metal concentrations in leachates occurring well before a pore volume of water had passed through the lysimeters. The study also revealed considerable differences between different soil types in the extent of metal leaching. It should be noted that the amounts of metals leached represented a very small fraction of the metals applied to the soil. Nevertheless, the cumulative effect of several decades of leaching has the potential to substantially influence the concentrations and distribution of trace metals in the soil.

2.3.6 INTERACTIONS BETWEEN CONTAMINANTS

Plants require a balance of elements for their proper growth and development, and imbalance between elements may cause chemical stress. Imbalances may result from both antagonistic and synergistic effects operating within the plant, or may influence absorption of elements from the soil. Antagonism between elements occurs when the combined effect of two or more elements is less than the sum of their independent effects, and synergism occurs when the combined effects of the elements is greater. Interaction processes are controlled by several factors and the exact mechanisms are still poorly understood, although some data are available (Kabata-Pendias and Pendias, 2001).

Interactions have been observed between major elements and trace metals, and between different trace metals. However, the interrelationships between elements are extremely complex, being at times both antagonistic and synergistic (see Figure 2-3), and often difficult if not impossible to predict. Unfortunately, many of the studies in which metal interactions have been observed have been carried out under conditions, or at metal concentrations, that have little practical relevance.



Source: Kabata Pendias and Pendias, 2001

Figure 2-3 Interactions of trace elements within plants and adjacent to plant roots

2.3.6.1 IMPLICATIONS OF METAL INTERACTIONS FOR BIOSOLIDS APPLICATIONS

When recommendations for the regulation of zinc, copper and nickel in biosolids-amended soils were first established in the UK (Chumbley, 1971), they implied that the phytotoxic responses of these three metals were additive (the zinc equivalent concept). However, subsequent experimental work has suggested that the toxicity to these metals was not additive but acted independently for each metal below the critical plant tissue concentration values (Beckett and Davis, 1982). Certainly most recent reviews of research in this area have concluded that synergistic interactions between trace metals are not commonly observed (e.g., Smith, 1996; Kabata-Pendias and Pendias, 2001).

In contrast, antagonistic effects are likely to be more common. In particular, zinc is commonly documented as being a competitive inhibitor of the plant uptake of cadmium (e.g., Chaney and Oliver, 1996). Since zinc concentrations in biosolids are usually much higher than cadmium concentrations, the antagonism between these metals is generally regarded as likely to restrict plant uptake of excessive cadmium. Other antagonistic reactions may also occur between iron, manganese, copper and zinc (Kabata-Pendias and Pendias, 2001), but would appear to be impossible to predict.

One type of interaction that takes place in soil may be of particular significance for biosolids applications. It has been proposed that the iron, manganese and aluminium present in biosolids may be oxidised in the soil to form oxide or hydrous oxide minerals (if not already present in these forms), which are then capable of adsorbing other metals, thus reducing their solubility, mobility and bio-availability (Corey et al., 1987). Some data from long-term biosolids plots have indeed been interpreted in this way (Chaney and Oliver, 1996). However, data for New Zealand sewage sludges

(Ogilvie, 1998) would suggest that iron, manganese and aluminium concentrations are generally not high enough for such an effect to be significant.

2.3.7 BIOSOLIDS PROPERTIES

Biosolids can vary greatly in their properties and the type and concentrations of contaminants present, depending on the sources of wastewater entering the treatment plant and the nature of the treatment process. Biosolids material applied to the land can range in physical composition from liquid sludges with less than 10% solids, to dewatered materials (essentially solid, but still with a high moisture content), to completely dried and pelleted material. Biosolids may also be composted with other organic wastes to produce materials with a similar physical composition to garden compost. Clearly the physical nature of the material will affect the ease of handling, and influence the machinery used to apply it to the land.

In addition to the variation in the types and concentrations of contaminants present, there are also substantial variations in the concentrations of beneficial nutrients (e.g., nitrogen, phosphorous, sulphur, potassium, calcium and magnesium). Thus, not surprisingly, the usefulness of particular types of biosolids as fertiliser material will be affected by their actual composition. There is also considerable variability in the inorganic components of biosolids: most materials will contain a substantial proportion of fine silt and clay particles, and possibly iron, aluminium and manganese either as oxides or that become oxidised in the soil. The potential effect of these constituents on metal bio-availability and mobility has been discussed earlier. The forms in which trace metal contaminants occur in the biosolids can also vary markedly (e.g., Steinhilbler and Boswell, 1983; Oake et al., 1984), depending on the other properties of the materials. However, there is considerable contradiction in the literature concerning the importance of such differences in modulating the bio-availability and mobility of metals in treated soils (Smith, 1996).

Some research would suggest that in the short term metal bio-availability may well be significantly influenced by biosolids properties such as pH, organic matter content, inorganic constituents, and the forms of metals (e.g., John and Laerhoven; 1976; Jing and Logan, 1992). However, other research suggests that with time, differences between biosolids disappear as the material becomes incorporated into, and reacts with, the soil (e.g., Mitchell et al., 1978; Berrow and Burrige, 1984). Without considerable further research in this area, our ability to predict likely metal bio-availability or mobility trends on the basis of biosolids properties will remain extremely limited.

2.3.8 EFFECT OF LAND MANAGEMENT ON CONTAMINANT BIO-AVAILABILITY AND MOBILITY

Land management can have a significant effect in minimising the potential for adverse effects from the application of biosolids to land. Sound management strategies must be based on a good understanding of the way the contaminants present in biosolids react with the soil (as discussed above). They should be aimed at minimising the bio-availability and mobility of contaminants and thus reducing their likely movement into the food chain, or transfer into ground or surface waters.

2.3.8.1 APPLICATION STRATEGIES

Biosolids should only be applied to soils in ways, and under conditions, that will ensure they remain in place and do not move off-site. Sufficient buffer zones should be left to ensure that sensitive areas, like waterways, are not directly affected. The climatic conditions during application also need to be taken into account to ensure that biosolids cannot be blown or washed onto non-target areas. Clearly this will depend to a certain extent on the actual method used for application, and the physical nature of the biosolids material, particularly its moisture content. Ideally, incorporation of biosolids into the soil will minimise losses during application and ensure good contact with the soil, thus placing contaminants in close proximity to sites where immobilisation reactions can occur. Biosolids applications remaining on the land surface may be subject to run-off, so steeply sloping sites should be avoided.

2.3.8.2 NATURE OF THE SOIL

Soils in New Zealand are extremely variable and range greatly in their ability to sustain both the short-term and long-term application of biosolids. There are a number of individual soil chemical and physical properties that will determine the suitability of a soil to receive applications of biosolids. The ability of the soil to tightly retain contaminants is clearly important, and this predominantly depends on soil organic matter content, oxide (iron, aluminium and manganese) content, clay content and soil pH. In general, the greater the amounts of these constituents in the soil, and the higher the soil pH, the greater the contaminant retention capacity. For metals, the cation exchange capacity of the soil provides a useful estimate of retention capacity.

Poorly drained soils should be avoided since application machinery is likely to cause structural damage to the soil, and the possibility of surface run-off of material will be greater than for freely drained soils. In addition, decomposition of the organic matter in the biosolids is likely to be slow under saturated soil moisture conditions. At the other end of the scale, excessively drained coarse-textured soils may need to be avoided when considering sites for biosolids application. Such soils usually have low contaminant retention capacities, so that leaching of contaminants down through the soil profile is a distinct possibility. However, the importance of this will depend on the extent of drainage through the soil (in low rainfall areas this may not be a problem), and whether significant concentrations of contaminants are likely to reach aquifers or other water bodies used as sources of potable water, or that have particular environmental significance.

2.3.8.3 LAND USE

The use of biosolids as a fertiliser/soil conditioner for the growth of annual crops, where the biosolids can be incorporated into the soil prior to sowing, is probably the most advantageous way of utilising this material. However, incorporation into the soil is not usually an option for permanent crops such as forests and orchards, or pastures. In these situations, care must be taken to avoid the potential problems associated with surface application discussed above.

An additional problem at forest sites is often the low pH of the soils, since this promotes metal solubility and therefore the potential leaching of metal contaminants. Clearly, the drainage regime of these soils and the depth and proximity of local aquifers will be important considerations determining the use of biosolids in forest soils.

2.3.8.4 SOIL PH MANAGEMENT

As discussed above, soil pH affects both the retention and solubility of metals in the soil. Therefore pH has an important effect on both the bio-availability and mobility of metals in biosolids-amended soils. Indeed, it has been argued that soil pH is the single most important soil property controlling the availability of metals in biosolids-treated soils (Smith, 1996). The main metal contaminants (cadmium, chromium, copper, nickel, lead and zinc) are present in the soil predominantly as cations, and thus tend to become more soluble and bio-available as soil pH decreases (soil becomes more acidic). For this reason, overseas guidelines and regulations for biosolids sometimes restrict application of biosolids to agricultural soils above a particular pH value, or adjust the maximum permissible metal loadings according to soil pH (e.g., UK Statutory Instrument, 1989). There is some debate as to what constitutes the appropriate lowest soil pH for biosolids application, with values generally ranging from pH 5.0 to 6.5. Research in this area has been reviewed in detail by Smith (1996), and suggests that plant bio-availability of cadmium, nickel and zinc in particular can increase substantially below pH 5.5.

Maintaining the pH values of biosolids-treated agricultural soils between pH 5.5 and 6.5 is likely to minimise the risk of phytotoxicity, or excessive metal uptake by crops. Normal agronomic liming practices should ensure this, but soils do tend to become more acid with time so that regular pH monitoring of biosolids-amended soils should be carried out. In the short term, because some biosolids may have a high pH (7.0 and above), their application to the soil may actually increase soil

pH. However, decomposition of the organic matter in biosolids and nitrification of mineralised ammonium will eventually have an acidifying effect.

In contrast to the metal cations, the bio-availability of the anionic metals molybdenum, arsenic and selenium generally increases with pH. However, the concentrations of these metals in New Zealand biosolids are not usually high, so that maintaining soil pH values above 5.5 is not likely to create problems.

Unlike agricultural soils, forestry soils are not usually limed to maintain soil pH, and many forest soils are naturally acidic, with pH values less than 5.0. Although, applying biosolids to forest soils under such low pH conditions could appear to represent a potential problem in terms of high metal bio-availability and mobility, this is not necessarily the case. Since food crops are not involved, plant uptake of metals is not a concern and trees do not appear particularly sensitive to metal phytotoxicity. Some of the more mobile metals (e.g., nickel and zinc) may be leached from biosolids-treated forest soils (Sidle and Kardos, 1977; Cameron et al., 1994) but this seems unlikely to represent a serious environmental threat. In a recent lysimeter study in which metal-spiked biosolids were applied to the surface of three forest soils at the Department of Health's 1992 guideline soil metal limits, the leachate metal concentrations, although increased by the biosolids application, generally remained below maximum acceptable values for drinking water (McLaren et al., 1999).

2.3.8.5 ANIMAL GRAZING

The management of grazing animals on land treated with biosolids is a controversial issue. Clearly, to avoid pathogen problems, withholding periods are required before allowing grazing animals on biosolids-treated land. However, there is also the potential for animals to ingest contaminants by consuming plants that contain elevated concentrations of contaminants, or by ingestion of the soil itself. Soil intake occurs either by (i) ingesting soil (or biosolids) present on the surface of plant leaves, or (ii) ingesting soil (or biosolids) directly from the soil surface or attached to plant roots (Healy, 1973). As a result, surface application of biosolids to established pastures is unlikely to be a realistic option. Incorporation of biosolids into the soil when pastures are re-sown should substantially reduce the ingestion of contaminants by grazing livestock.

The potential for adverse effects of metal contaminants on animals grazing on biosolids-treated soils has been reviewed by Smith (1996). He concluded that there was little evidence that animal health could be seriously affected by direct ingestion of sludge-amended soil. However, some caution should probably be applied to this conclusion, which was made in the absence of any substantial long-term field studies involving grazing animals. Irrespective of the potential or actual effects of metal-contaminated soils on animal health *per se*, there appears to be general agreement on the accumulation of metals in animal tissues. Most studies with animals have shown no accumulation of contaminant metals in muscle tissues, but increased concentrations of copper, lead and cadmium in animal livers or kidneys appear to be quite common. For example, Hill et al. (1998a,b) observed the accumulation of cadmium and lead in the livers and kidneys of sheep fed diets that included soil contaminated with sewage sludge. Similarly, Roberts et al. (1994) have reported the accumulation of cadmium in sheep kidneys from low-level soil contamination by phosphate fertilisers in New Zealand. This has resulted in the New Zealand Meat Industry automatically condemning kidneys of slaughtered animals over 2.5 years of age (Roberts et al., 1994), in spite of the fact that the consumption of offal products probably forms a negligible proportion of most people's diet.

The direct ingestion of biosolids-treated soil by grazing livestock is also considered to be the principal route of organic chemical accumulation in the food chain (e.g., Fries, 1982). However, reliable data in this area are somewhat scarce and contradictory. According to Smith (1996), "more data is needed to fully quantify the potential risk to grazing animals of organic pollutants in sludge surface-spread on grassland, although current information suggests the risk is likely to be small". Smith also noted that "it is widely recognised, however, that sludge injection *into the soil* can virtually eliminate problems of animal ingestion of organic contaminants".

2.3.8.6 CLIMATE

Some of the risks associated with biosolids discussed above will undoubtedly be affected by climate. Rainfall, in particular, can be an important consideration. Application of biosolids to the land under excessively wet conditions will increase the potential for surface run-off, and also possibly macropore flow through soils. Damage to soil structure may also occur as a result of compaction due to the passage of heavy application machinery over the soil. This in turn may lead to surface ponding and anaerobic conditions. Clearly, the application of biosolids under such conditions should be avoided.

Annual rainfall and associated soil drainage may also be factors to consider when assessing the suitability of land for biosolids application. For example, to minimise contaminant leaching it may be necessary to avoid shallow or coarse-textured (sandy) soils in areas with high rainfall. The same types of soil, however, may be quite suitable for biosolids application, and indeed provide substantial benefits in drier regions.

2.4 SOIL CONTAMINANT LIMITS

The 2003 Biosolids Guidelines provided a detailed review and background to their soil metal limits which represented a further development from the Department of Health's 1992 soil limits, which were in turn derived from limits used in the UK. These limits have since been further revised and published e.g. *Envirolink Tools Grant: C09X1402*. Refer <http://www.envirolink.govt.nz/envirolink-tools/> and the Ministry for the Environment National Environmental Standard for Assessing and Managing Contaminants in Soil to Protect Human Health, April 2012, publication reference number: ME1092. Refer <http://www.mfe.govt.nz/publications/>

To avoid confusion the 2003 Biosolids guideline technical information on soil metal limits is therefore not repeated here.

2.5 STABILISATION ISSUES

2.5.1 INTRODUCTION

Stabilisation of biosolids is achieved by treating them in such a way as to reduce or eliminate the potential for putrefaction, which as a result reduces pathogens, vector attraction and offensive odours. Therefore, although only one letter (A or B) is used to represent the stabilisation grade, to achieve this grade, a combination of pathogen, vector attractant reduction and odour reduction must have taken place. This can be achieved by the use of just one treatment process or a combination of different processes. However, the length of time a process needs to be operated for, or the temperature maintained, may be different for pathogen reduction than for vector attractant reduction.

The following section discusses what is meant by pathogen and vector attractant reduction, as well as giving the treatment requirements for achieving the stabilisation Grade A or B. The different types of treatment process commonly used to produce biosolids in New Zealand are also discussed, as are their probable effectiveness in achieving a reduction in pathogens and/or the vector attractant properties of the final product.

2.5.2 PATHOGEN REDUCTION REQUIREMENTS

A pathogen is an organism that can cause disease in humans. There are five main types of pathogens observed in biosolids: bacteria, viruses, fungi and yeast, parasitic worms and protozoa (EC, 2001a). Many different processes can be used to reduce the number of pathogens present in biosolids prior to their use.

This document does not seek to recommend specific processes to reduce pathogens, but instead concentrates on proven relationships (e.g., time/temperature) that need to occur during the biosolids production process. How producers of biosolids choose to meet these requirements is up to them. This approach should enable the development of new procedures and not limit producers to specific technologies.

2.5.3 VECTOR ATTRACTANT REDUCTION (VAR)

Here the term 'vector' refers to potential carriers of disease, such as flies, mosquitoes, birds and rodents. In order to meet both Grade A and B stabilisation standards, the biosolids must have been treated in such a way as to reduce their attractiveness to these disease carriers; this process is known as vector attractant reduction (VAR). In the context of biosolids, VAR can be achieved by either:

- ♦ reducing the attractiveness of the biosolid to vectors, by biological processes or specific chemical and physical conditions; or
- ♦ by removing access to the biosolid from vectors, usually by incorporation of the biosolid into soil shortly following application (within a matter of hours).

High-quality biosolids are those in which vector-attracting compounds, such as volatile solids, have been reduced or removed. This is because reducing vector attraction effectively decreases the risk to public health presented by the biosolid.

VAR methods can apply to both biosolid manufacturing processes and land application processes. In terms of the unrestricted use category, the VAR treatment of the biosolids should occur during the manufacturing process rather than during the application process. This is because the application to land of biosolids in the unrestricted use category is, by definition, uncontrolled.

VAR should take place either at the same time as pathogen control or just after it. VAR control measures should also be taken during storage of biosolids. Adhering to this management practice will also reduce regrowth of pathogenic bacteria. Six ways are suggested for reducing the attractiveness of biosolids to vectors.

2.5.4 BIOSOLIDS STABILISATION REQUIREMENTS

Pathogen reduction and vector attraction reduction requirements necessary to achieve either stabilisation Grade A or B are summarised in Table 2-3. These have been derived from the USEPA Rule 503 requirements (USEPA, 1993) and the NSW EPA (1997) stabilisation grading.

To achieve a stabilisation Grade A, the biosolids must meet one of the pathogen reduction criteria *and* one of the VAR criteria as well as having an *accredited* quality assurance process. The biosolids must also meet the pathogen levels (given in Table 2-4) after processing but before application.

To achieve a stabilisation Grade B the biosolids must meet at least *one* of the six VAR criteria specified for Grade A. There is no requirement for a producer of Grade B biosolids to demonstrate compliance with a pathogen reduction criterion. This is because there are no numerical pathogen limits set for Grade B biosolids, which is in line with NSW EPA requirements. There is also no requirement for the quality assurance process to be accredited in order for the product to achieve a Grade B. However, it is recommended that documented quality assurance procedures be independently verified for Grade B. Good management practices strongly support quality assurance procedures for all production facilities, and these *Guidelines* support and recommend this approach.

Table 2-3 Stabilisation requirements

Grade	Acceptable pathogen reduction processes	Acceptable VAR and odour reduction methods
Grade A	Accredited quality assurance plus one pathogen reduction process from the 3 options below:	Accredited quality assurance plus
	<p>1. Time–temperature process</p> <p>a) $\geq 7\% \text{ DS}$</p> <p>Within the relationship $t = \frac{131,700,000}{10^{0.14T}}$; t = days, T = °C, where T $\geq 50^\circ\text{C}$ and t ≥ 15 seconds, or</p> <p>b) $< 7\% \text{ DS}$</p> <p>Within the relationship $t = \frac{50,070,000}{10^{0.14T}}$; t = days, T = °C, where T $\geq 50^\circ\text{C}$ and t ≥ 30 minutes, or</p>	at least one VAR/odour method from the list below: <ol style="list-style-type: none"> 1. mass of volatile solids in biosolids shall be reduced by a minimum of 38%^c; or 2. biosolids $\geq 90\% \text{ DS}$ if heat dried at T $> 80^\circ\text{C}$; or 3. T $\geq 40^\circ\text{C}$ for ≥ 14 days and $T_{\text{ave}} \geq 45^\circ\text{C}$; or 4. SOUR @ $20^\circ\text{C} \leq 1.5 \text{ g/m}^3$ for liquid sludges from aerobic processes; or 5. pH ≥ 12 @ 25°C for at least 2 hours and pH ≥ 11.5 for 22 more hours; or 6. soil incorporation.
	<p>c) Composting^a</p> <p>(i) In-vessel: T $\geq 55^\circ\text{C}$ for ≥ 3 days, or (ii) Windrow: T $\geq 55^\circ\text{C}$ for ≥ 15 days with a minimum of 5 turnings during this period.^b</p>	
	<p>2. High pH – high temperature process</p> <p>pH > 12 (measured at 25°C) for ≥ 72 hours, and maintain T $> 52^\circ\text{C}$ for 12 consecutive hours within the 72 hours, all from the same chemical application and drying to $> 50\% \text{ DS}$ afterwards.</p>	
	<p>3. Other processes</p> <p>Demonstration by agreed comprehensive process and product monitoring that the Grade A pathogen levels can be consistently met.</p>	
Grade B	Verified quality assurance plus Storage and/or restricted access (see Table 2-5).	Verified quality assurance plus one of the VAR requirements from Grade A.

^a All compost must have 30 days maturation pre-use.

^b 5 x 3 days at T $\geq 55^\circ\text{C}$ plus time periods to reach 55°C after each turning.

^c Based on representative samples before and after the reduction process.

2.5.5 PATHOGEN STANDARDS

The pathogen standards detailed here have been determined after a review of the pathogen requirements of the USEPA (1993), NSW EPA (1997), NRMCC (2003), Department of Health (1992) and the Wellington Regional Council Living Earth Joint Venture (LEJV) consent.² In the case of a guideline proposing more than one standard (e.g. USEPA), the standard for the highest-quality biosolid was used in the review.

Standards have been set for faecal coliforms, salmonella, campylobacter, enteric viruses and helminth ova.

Table 2-4 Pathogen standards¹

Pathogen	Verification sampling	Routine sampling
<i>E. coli</i>	< 100 MPN ² /g	< 100 MPN/g
<i>Campylobacter</i>	< 1/25 g	N/A ⁴
<i>Salmonella</i>	< 1/25 g	N/A
Enteric viruses	< 1 PFU ³ /4g	N/A
Helminth ova	< 1/4g	N/A

¹ In the event that one of the samples fails to meet the product verification standards specified, all of the pathogen tests for that sample must be repeated. One hundred percent compliance must be achieved in order to meet the stabilisation grade standard. (In the case of biosolid manufacturing facilities in existence prior to the publication of these *Guidelines*, it is acceptable to use data up to 12 months old for the purposes of product verification. Older data cannot be used).

² MPN = most probable number.

³ PFU = plaque forming unit.

⁴ Not applicable.

The rationale for each pathogen standard set is as follows.

2.5.5.1 ESCHERICHIA COLIFORMS (E. COLI)

The LEJV consent for the Wellington biosolids plant was set at < 200 MPN/g, which mirrors the Department of Health (1992) Category II requirement. The draft NRMCC (2003) guideline sets a lower limit of < 100 MPN/g, while USEPA and NSW EPA set a much higher limit of < 1,000 MPN/g. Only the USEPA gives a reason for the setting of its limit, which is that this level of coliforms has been shown to correlate with low numbers of salmonella. The USEPA is therefore the only agency to give the option of measuring *either* coliforms *or* salmonella, but there is no requirement to monitor both.

2.5.5.2 CAMPYLOBACTER

Whereas *Salmonella* spp. are traditionally used as an indicator for pathogen removal, the high incidence of campylobacter infection in the New Zealand community makes it a greater risk. For this reason campylobacter is required for verification sampling.

² It should be noted that the EU directive (CEC, 1986) does not contain any standards for pathogen numbers, although four member states have chosen to implement standards for several pathogens in their own domestic legislation.

2.5.5.3 SALMONELLA

The limit given here is based on the requirement of the LEJV consent figure of 1/25g. The limits given in USEPA (1993), NRMCC (2003) and NSW EPA (1997) are less stringent than this, but no reasoning could be found for any of the standards reviewed. For this reason it was determined that the LEJV consent requirement was effectively a New Zealand-based standard and that this should be reflected in these *Guidelines*. The requirement to analyse the biosolids for salmonella applies only to verification sampling.

2.5.5.4 ENTERIC VIRUSES

The limit of < 1 PFU/4g biosolid is based on USEPA (1993) and NSW EPA (1997) requirements. The LEJV consent is very similar at 1 PFU/4g. In these *Guidelines* the requirement to analyse the biosolids for enteric viruses only applies during the initial verification period. If the pathogens are present at numbers less than the standard the requirement to monitor them during routine sampling should be dropped. This is in line with the USEPA requirements and the LEJV consent. This type of test is expensive and the results can take up to four weeks to obtain, which is significant given that the biosolids cannot be sold until the sample results are known.

2.5.5.5 HELMINTH OVA

The limit of < 1/4g has been derived from the USEPA (1993). The LEJV consent has been set at 1/4g and the NSW EPA (1997) is similar with 1 PFU/4g. The use of PFU in conjunction with helminth ova was considered unusual, which is why it has not been used here. As with enteric viruses, the requirement to analyse the biosolids for helminth ova only applies during the initial verification period. If the pathogens are present at numbers less than the standard the requirement to monitor them during routine sampling should be dropped. This is in line with the USEPA requirements and the LEJV consent. This type of test is expensive and the results can take up to four weeks to obtain, which is significant given that the biosolids cannot be sold until the sample results are known.

2.5.5.6 CRYPTOSPORIDIUM/GIARDIA

These are a known problem in New Zealand, and process controls should render them non-viable. Current test methods are not yet sufficiently reliable to warrant setting standards for biosolids. If reliable test methods are established then standards should be considered.

2.5.6 TREATMENT PROCESS OPTIONS

Biosolids producers have access to a wide range of treatment processes to enable them to meet the different stabilisation grades of biosolids recommended in these *Guidelines*. Some of these processes are effective at reducing both pathogens and vector attraction, whereas others may be better at one or the other. In the latter case it may sometimes be necessary to combine different treatment processes to ensure that the final product achieves a specific stabilisation grade. These treatment processes do little to change the mass of contaminants, but concentrations may increase due to reductions in volatile solids, and/or decrease due to the addition of chemicals (e.g., lime).

There are five broad approaches to controlling pathogens in biosolids:

- high temperatures;
- radiation;
- chemical disinfectants;
- reducing volatile organic content; and
- removing moisture.

Within these five approaches there are a number of different types of processes and technologies, some of which can be categorised under more than one approach. These processes and the approaches they are based on are briefly discussed below.

2.5.6.1 PASTEURISATION

Pasteurisation involves heating the sludge to a temperature of 70–80°C for approximately 30 minutes. This treatment will reduce the number of pathogens, but it cannot be considered a stabilisation process in its own right and is usually used in conjunction with other processes, such as mesophilic digestion.

Pasteurisation can be achieved by using heat exchangers or steam injection. In theory the addition of quicklime (an exothermic or heat-producing reaction) could result in pasteurisation, but this is a very difficult process to control as it requires thorough mixing. Odour can be an issue with pasteurised biosolids because the process does not stabilise organic matter but increases the soluble volatile content.

2.5.6.2 IRRADIATION

Irradiation of sewage sludge reduces pathogens by disrupting their cell content, which either destroys the organism or prevents it from reproducing. The irradiation used can be gamma or beta ray-based, and its effectiveness relates to the length of dose applied to the sludge. Although irradiation is commonly used as a pathogen reduction technique in several countries in Europe, it is not used in the US or New Zealand.

2.5.6.3 LIME STABILISATION

Lime stabilisation of sewage sludge to form biosolids works by raising the pH to 12 or more, which has the effect of destroying or inhibiting the pathogens present. However, the effectiveness of this treatment process is related to the length of time the pH is constantly above 12. Lime can be added to liquid sludge or to dewatered sludge, but effective treatment depends on adequate mixing of the lime with the sludge to ensure the pH is raised uniformly. The addition of lime to sludge also has the benefit of increasing the level of dry matter present and making handling of the final product easier.

The main problem associated with lime stabilisation is the development of odours if the pH falls below 10.5; this is particularly an issue following land application. Soil incorporation of the biosolids as part of the application process can overcome this.

Lime stabilisation is effective in reducing bacteria and viruses as well as reducing vector attractant properties. Protozoan cysts may be inactivated, but the addition of lime is not thought to be effective on helminth ova, unless combined with heat (USEPA, 1999).

2.5.6.4 COMPOSTING

Composting is an aerobic process, which involves mixing treated sludge with a co-product such as sawdust, green waste or wood chips³. The co-product provides a source of carbon, increases porosity (and therefore oxygen flow) and absorbs moisture. Heat generated as a result of the aerobic biological activity that takes place destroys the pathogens in the sludge.

Organic material will compost on its own over time without any control, but the use of composting as a biosolids treatment process must be carefully designed, controlled and managed to ensure appropriate time/temperature criteria are achieved throughout the process. There are three types of composting process.

- ♦ *Windrow* – the sludge/co-product mixture is placed in long rows, which are turned periodically to introduce air, reduce moisture levels and maintain even temperatures.
- ♦ *Aerated static piles* – the sludge/co-product mixture is laid over perforated pipes, through which air is blown or sucked. This introduces oxygen, which aids decomposition and also

³ Treated timber must not be used as a co-product (see section 3.5.3).

reduces moisture. If the air is sucked through the compost rather than blown it can also help odour control.

- ◆ *In-vessel systems* – there are many different types of vessel system in use, but all operate under carefully controlled conditions, including active aeration.

Composting, if conducted under the right conditions, is effective at reducing bacteria, viruses, helminth eggs, protozoa, vector attraction and odour. Composting also reduces the water content in the final product to as much as 60% dry matter, which makes handling much easier and results in a commercially attractive product.

Research by the USEPA (1999) has found that windrow composting may not be as effective at pathogen reduction as in-vessel and aerated static-pile composting. Specific guidance has been given by the USEPA (1999) to improve the effectiveness of the windrow process.

While pathogen and VAR can be achieved without a curing process, such a process can enhance odour reduction.

2.5.6.5 ANAEROBIC DIGESTION

Anaerobic digestion is undertaken in closed tanks in the absence of oxygen and with or without additional heating. There are two types: high-rate, which involves mechanical mixing and heating of the sludge, and standard-rate, which is generally conducted at ambient temperature with no mechanical mixing. The majority of plants use high-rate digestion. Both types of anaerobic digestion result in a reduction of volatile solids of between 40 and 50% according to EC (2001b) and between 35 and 60% according to USEPA (1999). This reduction in volatile solids reduces the likelihood of regrowth of pathogens after treatment.

Depending on how the system is managed, anaerobic digestion can be operated in either a mesophilic ($\approx 35^{\circ}\text{C}$) mode or a combination thermophilic ($> 50^{\circ}\text{C}$) followed by mesophilic mode.

Methane is a by-product of anaerobic digestion, and this can be recovered and used to heat the process, thus reducing costs. Anaerobic digestion reduces bacteria, protozoa and viruses, although viable helminth eggs may not be significantly affected.

2.5.6.6 AEROBIC DIGESTION

Aerobic digestion of sludge is carried out in either open or closed vessels. In order to supply enough oxygen to the bacteria in the sludge, the mixture either has to be agitated or have air injected into it. Heat is generated when the bacteria present break down organic matter to carbon dioxide, nitrate nitrogen and water. Depending on how the system is managed, aerobic digestion can operate in either the mesophilic or thermophilic temperature ranges. If operated correctly, aerobic digestion can result in a 40% reduction of volatile matter in the mesophilic range, and up to a 70% reduction if thermophilic aerobic digestion is used. It is also effective at reducing bacteria, protozoa, viruses and helminth eggs, although the latter is more effective at the higher temperatures associated with thermophilic aerobic digestion.

The operation of an aerobic digester can either be batch or continuous. The length of time the sludge needs to remain within the digester for effective pathogen reduction to take place, irrespective of the process used, is based on the temperature the process is operating at.

2.5.6.7 THERMAL AND AIR DRYING

In air drying, the sludge is applied to a sand or gravel bed and allowed to dry naturally over a period of months. During drying, biological processes take place, such as decomposition of organic matter, formation of ammonia and reduction in moisture, which in turn reduce bacteria, protozoa and viruses. Viable helminth eggs may also be reduced if the drying temperature is high enough, but this is dependent on the species involved, as some are much hardier than others.

Air drying is a simple process, but it requires a lot of land and is dependent on ambient temperatures for its effectiveness (higher temperatures are better). A dry matter content of up to 50% can be reached depending on local climatic conditions (EC, 2001b). Sludge should also be partially digested before it is applied to the drying bed. The USEPA (1999) has recommended that air drying be used as an additional process to aerobic or anaerobic digestion to meet the 38% volatile solids reduction requirement.

In thermal drying, sludge is dried by direct or indirect contact with heat. If conducted properly this has the effect of reducing bacteria, viruses, protozoa and viable helminth eggs. It is also effective at reducing VAR, provided the biosolids remain dry after treatment.

There are four main types of thermal driers: flash, spray, rotary and steam. All operate at different temperatures, and as a result the percentage dry matter in the final product can range from 35 to 90%. This type of treatment process results in a product that is greatly reduced in volume from the raw sludge, and can be applied to land like a mineral fertiliser.

2.5.6.8 LONG-TERM STORAGE

Long-term storage of sewage sludge will result in the reduction of bacteria and viruses present. However, the effectiveness of the process depends on the type of treatment prior to storage, and the length of storage time. It is unlikely that long-term storage would affect the viability of protozoa. The ambient temperature, with decreasing pathogen reduction at lower temperatures, also affects the efficiency of this process. Nitrogen levels in the sludge will also be reduced, which has the effect of reducing the agricultural value of the product.

Recommended controls for stabilisation Grade B biosolids and/or public protection using storage and exclusion periods (i.e. access restrictions) have been adapted from the Department of Health (1992) guidelines, and are summarised in Table 2-5.

Table 2-5 Recommended controls for stabilisation Grade B biosolids, depending on end use

Land use	VAR requirement	Recommended controls
Salad crops, fruit, other crops for human consumption that may be eaten unpeeled or uncooked	<ul style="list-style-type: none"> Mass of volatile solids in biosolids shall be reduced by a minimum of 38%; or SOUR @ 20°C ≤ 1.5 g/m³ for liquid sludges from aerobic processes; or pH ≥ 12 @ 25°C for at least 2 hours and pH ≥ 11.5 for 22 more hours. 	<p>May be applied immediately</p> <p>plus soil incorporation</p> <p>plus a further waiting period of at least 1 year before crops are sown (the land may be used for other purposes in the meantime).</p>
	<ul style="list-style-type: none"> Storage/restricted access 	<p>Store or lagoon for at least 1 year prior to application</p> <p>plus soil incorporation</p> <p>plus a further waiting period of at least 1 year before crops are sown (the land may be used for other purposes in the meantime).</p>
Public amenities, sport fields, public parks, golf courses, play grounds, land reclamation	<ul style="list-style-type: none"> Mass of volatile solids in biosolids shall be reduced by a minimum of 38%; or SOUR @ 20°C ≤ 1.5 g/m³ for liquid sludges from aerobic processes; or pH ≥ 12 @ 25°C for at least 2 hours and pH ≥ 11.5 for 22 more hours. 	<p>Store or lagoon for at least 6 months prior to application</p> <p>plus soil incorporation (</p> <p>plus restriction on public access for period of time necessary to establish a full vegetation cover on the land.</p>
	<ul style="list-style-type: none"> Storage/restricted access 	<p>Store or lagoon for at least 1 year prior to application</p> <p>plus soil incorporation</p> <p>plus restriction on public access for a period of time necessary to establish a full vegetation cover on the land.</p>
Fodder crops and pasture, orchards where dropped fruit is not harvested, turf farming, industrial or non-edible crops, crops that will be peeled or cooked before eating.	<ul style="list-style-type: none"> Mass of volatile solids in biosolids shall be reduced by a minimum of 38%; or SOUR @ 20°C ≤ 1.5 g/m³ for liquid sludges from aerobic processes; or pH ≥ 12 @ 25°C for at least 2 hours and pH ≥ 11.5 for 22 more hours. 	<p>May be applied immediately</p> <p>plus soil incorporation</p> <p>plus fruit and turf should not be harvested or pastures grazed for at least 6 months after applications</p> <p>plus crops that will be peeled or cooked should not be harvested for at least 6 months after application.</p>

Land use	VAR requirement	Recommended controls
	<ul style="list-style-type: none"> Storage/restricted access 	<p>Store or lagoon for at least 1 year prior to application</p> <p>plus soil incorporation</p> <p>plus fruit and turf should not be harvested or pastures grazed for at least 6 months after applications</p> <p>plus crops that will be peeled or cooked should not be harvested for at least 6 months after application.</p>
Forest, trees or bush scrubland	<ul style="list-style-type: none"> Mass of volatile solids in biosolids shall be reduced by a minimum of 38%; or SOUR @ 20°C ≤ 1.5 g/m³ for liquid sludges from aerobic processes; or pH ≥ 12 @ 25°C for at least 2 hours and pH ≥ 11.5 for 22 more hours. 	<p>May be applied immediately</p> <p>plus public access restricted for 6 months</p> <p>plus buffer zones should be fenced and signposted.</p>
	<ul style="list-style-type: none"> Storage/restricted access 	<p>Store or lagoon for at least 1 year prior to application</p> <p>plus public access restricted for 6 months</p> <p>plus buffer zones should be fenced and signposted.</p>

Source: Updated from Department of Health (1992).

Note: SOUR = standard oxygen uptake rate.

2.6 MONITORING AND QUALITY ASSURANCE

2.6.1 WHEN TO MONITOR?

2.6.1.1 MONITORING THE FINAL PRODUCT

Ideally, monitoring the quality of biosolids should occur just prior to their use. This practice is in accordance with the USEPA, European Union, NSW EPA and the NRMCC guidelines.

When determining the stabilisation grade, pathogen reduction monitoring should only be undertaken on the final product (just before sale), because pathogenic organisms may regrow after treatment has taken place. Producers of biosolids or products containing biosolids should be aware of this requirement, and ensure they have enough storage space to hold the product while waiting

for the results of monitoring. They should also inform the analytical laboratory of the need to complete the analysis as quickly as possible.

When determining the contaminant grade, it is not as important to undertake monitoring just before sale, as the concentrations of these parameters (i.e. metals and organic contaminants) are unlikely to change after treatment. However, if the products are to be mixed with another material (e.g., as part of a composting process or blending) before sale, then any monitoring should be undertaken on the final product.

2.6.1.1.1 TYPES OF MONITORING

The product monitoring process in these *Guidelines* is divided into two phases:

- ♦ verification monitoring; and
- ♦ routine monitoring.

Initially it was proposed that within these phases there would be distinct subsets of sample numbers relating to whether production was a batch process or a continuous process. This is the approach used in the NSW EPA (1997) guidelines. The reason for the different sampling protocols for continuous and batch-produced material is that the quality of each batch is not related to the quality of the other batches produced, whereas there is a form of quality consistency in the continuous process.

However, if a similar approach were adopted in these Guidelines, it would mean that batch producers would be required to take significantly more samples than producers who use a continuous process. As well as this being prohibitively expensive, it was also envisaged that confusion could arise as to which sampling regime was appropriate for those producers who use a semi-continuous process. For this reason it was decided to use a simplified system that would apply to all processes used.

Verification monitoring is the name given to the phase of monitoring undertaken when:

- ♦ a new plant is commissioned;
- ♦ process or equipment changes are made to an existing plant; and
- ♦ pathogen or chemical contaminant levels in the biosolids exceed the limits specified in these *Guidelines* (see Table 2-4).

Routine monitoring is typified by a less onerous sampling regime than that required for verification monitoring. This is because the product quality verification monitoring is used to demonstrate the ability and stability of the process and/or the quality of the product. Once these are determined to be satisfactory, the number of samples taken and the number of monitoring periods can be reduced.

2.6.2 NUMBER OF SAMPLES

The minimum number of samples that should be taken in each monitoring phase and for each grade are detailed in Table 2-6 and Table 2-7. Note that the sample numbers given are not designed to result in statistically representative data. This approach was felt unnecessary as the quality assurance controls comprise both process and product monitoring, so the product monitoring is a supporting indicator that the process is working correctly. In addition, the analytical cost of monitoring biosolids at a statistically representative frequency would be prohibitively high, effectively stymieing any beneficial use applications.

Table 2-6 Stabilisation grade sampling frequencies

Grade	Monitoring type	Sampling regime	Parameters to be monitored
A	Product verification ^{1,2}	≥ 15 evenly dispersed grab samples per month for a 3-month period with ≤ 3 failures. If > 3 failures then the 15 following consecutive grab samples must comply.	<ul style="list-style-type: none"> ▪ <i>E. coli</i> ▪ <i>Salmonella</i> ▪ <i>Campylobacter</i> ▪ enteric viruses ▪ helminth ova ▪ VAR
	Routine sampling	≥ 1 grab sample per week	<ul style="list-style-type: none"> ▪ <i>E. coli</i> ▪ VAR
B	Product verification ²	Not applicable for pathogen testing	<ul style="list-style-type: none"> ▪ VAR³
	Routine sampling	Not applicable for pathogen testing	<ul style="list-style-type: none"> ▪ VAR³

¹ No more than 3 samples should be taken per day during this period.

² In the case of biosolids manufacturing facilities in existence prior to the publication of these *Guidelines*, it is acceptable to use data up to 12 months old for the purposes of *product verification*.

³ If a barrier is to be used for VAR, no monitoring is required at the production stage.

Table 2-7 Contaminant grade sampling frequencies

Grade	Sample type	Number of samples
a and b	Product verification ¹	<ul style="list-style-type: none"> ▪ Metals: 1 composite²/week over a 3-month period ▪ Organics: 1 composite sample²/month over a 3-month period ▪ Dioxins: 1 composite³/3 months
	Routine sampling ¹	<ul style="list-style-type: none"> ▪ Metals: ≥ 1 composite²/2 weeks ▪ Organics: 1 composite²/2 months ▪ Dioxins: 1 composite/year⁴

¹ In the case of biosolids manufacturing facilities in existence prior to the publication of these *Guidelines*, it is acceptable to use data up to 12 months old for the purposes of *product verification*. For the purposes of determining compliance at the 95 percentile for *routine sampling*, the age of the data set shall be no more than 2 years for metals and organics (i.e. organochlorine pesticides and PCBs) and no more than 5 years for dioxins. This avoids the scenario of old data masking upward trends in contaminant concentration.

² Samples tested should be made up from daily composites. For organics verification sampling, there shall be no exceedence over 3 consecutive samples.

³ The dioxin verification composite should be made up of 1 sample taken per day during the verification period.

⁴ The dioxin routine composite is to be made up of 1 sample per week over a year-long period.

2.6.2.1 STABILISATION GRADE SAMPLING

When monitoring for pathogens it is important that the samples taken are grab samples. Composite samples are not used because the risk of exposure to pathogens is not cumulative. For the same reason, the actual values from each grab sample need to be reported – not the average. This is in alignment with the USEPA recommendations for pathogen monitoring of a Class A product.

During the process verification period a total of three failures is allowed. If this number is exceeded, then the next 15 grab samples must comply. If any of the failures occur during the last month of verification sampling (i.e., there are fewer than 15 samples left to take), samples must continue to be taken at the verification frequency until 15 consecutive compliant samples have been obtained. It is therefore possible that the verification period may involve more than 45 samples.

Once the verification monitoring has been completed, the sampling regime can change to the one specified under the routine monitoring regime (i.e., at least one grab sample per week). If any of these samples fail, then, for stabilisation Grade A, a return to the verification monitoring regime for all pathogens is required to ensure product quality.

The samples taken during the verification period must be analysed for *E. coli*, salmonella, campylobacter, enteric viruses, helminth ova and vector attraction reduction. Once it has been confirmed that the product is of a consistent quality, then, for Grade A, routine samples only need be analysed for *E. coli* and vector attraction reduction. For Grade B, there is only a requirement for VAR monitoring during routine biosolids production, unless a barrier is to be used for VAR in which case no monitoring is required.

2.6.2.2 CONTAMINANT GRADE SAMPLING

A review of existing biosolids literature indicates that there are three approaches taken to contaminant monitoring.

- *EU* – after initial sampling to determine a baseline (no numbers given), one sample every six months for metals listed in the directive. No organics monitoring is required. (CEC, 1986).
- *USEPA* – the number of samples taken for contaminant monitoring is based on the amount of biosolids produced. Sampling rates vary from once to 12 times per year (USEPA, 1993).
- *NSW EPA* – the number of samples is based on a combination of production process (batch or continuous) and previous results obtained (NSW EPA, 1997).

To determine the contaminant concentrations, the sampling regime detailed in Table 2-7 should be followed. This has been loosely based on the requirements of the NSW EPA. The approach taken in the NSW guidelines is very well documented and has been devised to ensure that biosolids products are graded and classified with an acceptable degree of accuracy. However, the actual methodology is very detailed and the number of samples required was considered excessive in the New Zealand context, particularly since the majority of New Zealand wastewater treatment plants are small (< 10 tonnes ds/day). The aim in these *Guidelines* is not to have sampling that is statistically representative on its own, but to use sampling as a means to show that process controls are working and that the *average* levels of contaminants in the biosolids are below the limits specified.

The USEPA approach was not thought appropriate for these *Guidelines*, as the bands used to classify biosolid production are very broad and not applicable to the scale of production in New Zealand. The bands only relate to the number of monitoring periods, not the number of samples. The only advice given on the number of samples to be taken is that they should be representative. The philosophy behind this approach is to ensure that monitoring requirements for small producers are not overly burdensome. No explanation could be found in the literature reviewed to indicate that there was any statistical reasoning behind the monitoring regime suggested. Similarly, no documentation was found that discussed the reasoning behind the EU approach.

Unlike the samples taken for stabilisation grade monitoring, samples taken for contaminant grade monitoring should be composite sample. Each composite sample should be made up of a number of grab samples taken from different locations and/or at different times. Composite samples are used because the chemical contaminants do not degrade and (compared with grab samples) this type of sample generally provides results that are more representative of the overall quality of the final biosolids product.

There is a less stringent requirement for dioxin sampling than there is for metals and the other organic contaminants, mainly because of the expense of this analysis. During the verification period one dioxin sample should be prepared which is made up of one sample per day taken over the three-month period. If this sample is compliant with the limits given in Table 7.2, then only one dioxin sample needs to be analysed annually. The sample taken under the routine monitoring regime should be a composite of one sample taken weekly over a year-long period. If the sample is not compliant, then full verification must be undertaken.

Irrespective of whether the samples are taken as part of verification monitoring or of routine monitoring, they should all be analysed for the contaminants given in Table 7.1 (metals) and Table 7.2 (organic contaminants).

If any contaminant fails (i.e. its concentrations exceed those specified in Tables 7.1 or 7.2), then a return to verification monitoring is required only for that contaminant. All other contaminants should continue to be monitored at the routine sampling frequency. The failed contaminant can only return to the routine sampling frequency once it is in compliance with the biosolids limits (Tables 7.1 and 7.2) from this additional verification sampling.

2.6.2.3 SOIL SAMPLING

Soil should be sampled *before* the application of biosolids to determine the existing contaminant concentration, and for bulk users of biosolids, every five years thereafter. In this way the accumulation of contaminants in the soil can be monitored.

Regular monitoring of soil is only recommended for the application of restricted use biosolids, as contaminant limits in unrestricted use biosolids are low enough to prevent the rapid accumulation of contaminants. However, periodic monitoring of soil that has had Aa grade biosolids applied to it would be useful and good management practice. These data should be collected centrally and held as a public record.

These *Guidelines* recommend a minimum of 10 soil samples per hectare be taken as part of any monitoring programme. Soil cores should be taken to a depth to which the biosolids were incorporated, up to a maximum of 200 mm. If there is no soil incorporation, the sampling depth should be 200 mm.

It is not necessary to monitor pathogen concentrations in the soil, as biosolid application will not cause a cumulative increase in pathogens.

2.6.3 FACTORS AFFECTING BIOSOLIDS APPLICATION

As a general rule it is recommended that biosolids (regardless of whether they are Aa, Ab, Ba or Bb grade) should not be applied to land that is:

- ◆ frozen solid;
- ◆ waterlogged;
- ◆ under snow;
- ◆ sloping steeply (e.g., >15%);
- ◆ in close proximity (say 20 m) to any watercourse, including a:
 - ~ river
 - ~ estuary

- ~ ocean
- ~ lake
- ~ reservoir
- measured as having a pH < 5.5.

If users wish to apply restricted use biosolids to sites that fall into one or more of the above categories, then the consenting authority should consider each resource consent application on its merits. There is no control over the use of unrestricted use biosolids. However, any label/information sheet that accompanies unrestricted use biosolids should include information relating to land types that are not suitable for application.

2.7 SAMPLING PROCEDURES

2.7.1 INTRODUCTION

Obtaining representative samples and maintaining their integrity are critical parts of any monitoring programme. Analytical methods have been standardised, but the results are only as good as the sample collection and preservation methods.

The USEPA has estimated that 95% of the total error in environmental measurements is due to sample collection and handling, and that only 5% is due to mistakes during laboratory analysis. The 95% can be further broken down into 85% of error from sample collection and 10% from sub-sampling in the laboratory (Rosecrance and Adolfo, 1996). This gives some indication of the importance of using correct sampling procedures at all times.

In sampling, the objective is to collect a small portion of an environment that is representative of the whole body. Once the sample is taken, the constituents of the sample must stay in the same condition as when they were collected.

2.7.2 SAMPLE TYPE

2.7.2.1 GRAB SAMPLES

A grab sample is one where the whole sample volume is collected at a particular time and place and represents the composition of the source at that time and place. Results from grab samples (also called 'spot' or 'catch' samples) can be said to represent the composition of a source product over a greater period of time *only* if the composition of the source is known to be relatively constant in space and time. Biosolids may not fall into this category, and so results from individual grab samples cannot be assumed to be representative of the sample source over time.

This is not to say that grab samples do not have their place in biosolids monitoring. Grab samples are essential if the aim of the sampling programme is to prove compliance with standards that are not related to average quality.

Grab samples should be used for determinands that deteriorate or change quickly after sampling, such as pathogens.

2.7.2.2 COMPOSITE SAMPLES

Composite samples are prepared by mixing a number of grab samples. They are very useful if there is thought to be much variability in the characteristics of the source being investigated. For this reason they are particularly useful for investigating biosolids. When the composite sample is analysed, the results give the average concentration for the parameter in question over the period of time the sample was collected.

Composite samples have an advantage over grab samples in that combining the individual grab samples for analysis means the laboratory costs are much lower. However, composite samples are not suitable for parameters that degrade/alter as a result of storage. In other words, composite sampling should only be used for components that can be shown to remain unchanged under the conditions of sample collection, preservation and storage. Consequently, composite samples should only be used for the chemical contaminants (i.e., metals, organics and dioxins) covered by these *Guidelines*. Composite sampling should *not* be used for monitoring pathogens.

2.7.2.3 MICROBIOLOGICAL SAMPLES

Special attention must be given to microbiological samples, because they are very susceptible to being contaminated by poor sampling technique. When taking a microbiological sample, the following must be taken into account:

- ◆ Containers and tools should be sterilised.
- ◆ The lids of sterile sampling containers should have a seal over them, which has to be broken before you take the sample. If this seal is damaged in any way, do not use the container as it may no longer be sterile.
- ◆ The container may have a use-by date on it. If it has and the date has passed, do not use the container as it may no longer be sterile.
- ◆ When taking the sample do not touch the neck of the container, or the inside of the lid. The lid must not be put down on any surfaces as this can contaminate the sample.
- ◆ When transporting microbiological samples, keep them separate from other non-sterile samples and cool with ice. Take care not to let melted ice come into contact with the container tops (this is best achieved by keeping the ice inside a plastic bag, separate from the sample container). Remember that even if the outside of the container is dirty, while it may not directly affect your sample it could contaminate the laboratory. Samples must not be exposed to direct sunlight and must reach the laboratory within the specified time limit.

If you have to take samples for microbiological analysis and you are unfamiliar with the aseptic technique, you must contact the laboratory for advice before collecting any samples. If you receive unexpected results from microbiological samples, remember how easy it is for poor sampling technique to affect the results before drawing any conclusions.

2.7.2.4 WHERE TO SAMPLE

In general, more representative sampling occurs when the biosolids being sampled are moving rather than stationary. However, this is not always possible. The USEPA have provided advice on the best locations for taking samples related to the type of biosolids involved. This is reproduced (slightly modified) in Table 2-8.

Table 2-8 Sampling points within processes

Process	Sampling point
Anaerobic digestion	Collect sample from taps on the discharge side of positive displacement pumps.
Aerobic digestion	Collect sample from taps on discharge lines from pumps. If batch digestion is used, collect sample directly from the digester. Note that when aeration is shut off, solids may settle rapidly.
Thickening	Collect sample from the taps on the discharge side of positive displacement pumps.
Heat treatment	Collect sample from the taps on the side of positive displacement pumps after decanting. Be careful when sampling heat-treated biosolids because of: <ul style="list-style-type: none"> ▪ a high tendency for solids separation ▪ the high temperature of the sample can cause problems with sample containers due to cooling and subsequent contraction of entrained gases.
Dewatering, drying, composting or thermal	Collect sample from material collection conveyors and bulk containers. Collect sample from many locations within the biosolids mass, and at various

Process	Sampling point
reduction	depths.
Dewatering by belt filter press, centrifuge, vacuum filter press	Collect sample from biosolids discharge chute or storage bin (see below).
Dewatering by biosolids press	Collect sample from the storage bin; select 4 points from within the bin, collect an equal amount from each point and combine to form one sample.
Dewatering by drying beds	Divide bed into quarters, grab equal amounts of sample from the centre of each quarter and combine to form a composite sample of the total bed. Each composite sample should include the entire depth of the biosolids material (down to the sand/drainage layer).
Compost piles	Collect sample directly from the front-end loader while material is being transported or stockpiled within a few days of use.
Sludge Ponds and WSPs	Composite of samples from representative grid pattern including variable depths ⁴ .

2.7.2.5 SAMPLE EQUIPMENT

The type of sample equipment chosen is usually dependent on the type of biosolids being sampled. However the following rules apply to all situations.

- Automatic sampling equipment (such as that used at wastewater treatment plants) is not suitable for sampling biosolids. All samples need to be taken manually.
- Equipment should be easy to clean and constructed of non-corrosive materials, such as Teflon, glass or stainless steel.
- Equipment used for biosolids sampling should not be used for any other purpose.
- Equipment should be well cleaned after use and stored in a clean location. It may be advisable to wrap any equipment between uses to ensure it stays clean.

For special requirements relating to the collection of microbiological samples, refer to section 2.7.2.3.

2.7.2.6 SAMPLE CONTAINERS

The following factors must be considered when choosing a sample container:

- high resistance to breakage;
- good sealing efficiency;
- ease of reopening;
- good resistance to temperature extremes;
- practicable size, shape and mass;
- good potential for cleaning – this is especially important for containers used to collect samples for microbiological analysis; and
- availability and cost.

Sample containers are generally made out of glass or plastic. The type of determinand the sample is to be analysed for often controls the type of material the container is made from, as some containers will react with the determinands and give false results when the sample is analysed. If you require a sample to be analysed for more than one determinand, you may have to use more than one type of sample container.

If you are unsure which type of container is required, the laboratory carrying out the analysis will be able to advise you.

⁴ Refer Waste Stabilisation Pond Good Practice Guide, Water New Zealand.

2.7.2.7 SAMPLE PRESERVATION

If a sample is to remain representative of the material from which it was taken, it is usually necessary to preserve the sample to prevent changes taking place during the period prior to analysis. This is particularly important for composite samples, which are going to be collected over a period of weeks and months.

The most common way of preserving samples is to cool the sample to between 0°C and 4°C. Once collected, samples should be stored at this temperature until analysis.

Biosolid samples can take a long time to cool down, and, as general rule, the thicker they are the longer they take to cool. Similarly, the larger the sample the longer it takes to cool. It is therefore practical to minimise the sample size to ensure rapid and effective cooling. Samples less than 4 litres in size should ensure this. Note that while freezing can be used to preserve some samples, this should not be done if the sample is to be analysed for bacteria. Freezing is not normally a standard preservation technique for samples to be analysed for metals or organic contaminants. If samples are to be frozen, they should not be collected in borosilicate glass containers, which are liable to fracture.

If the sample is being collected over an extended period of time the preservation of the sample should form an integral part of the collection procedure. Keeping the samples in the dark can enhance preservation further.

2.7.2.8 SAMPLE TRANSPORTATION

Samples to be analysed for microbiological parameters should be transported to the laboratory within six hours of collection. All other samples should be transported within 24 hours, unless suitably preserved. Sample transportation should be undertaken in accordance with standard quality assurance procedures, including the use of chain of custody forms.

2.7.2.9 LABORATORY SELECTION

A very important – but often overlooked – aspect of any monitoring programme is the selection of an appropriate analytical laboratory. Analysis of biosolids is a complex process because of the heterogeneous nature of the product. Therefore it is important to select a laboratory with experience in analysing this type of material.

In New Zealand the primary accreditation agency for analytical laboratories is International Accreditation New Zealand (IANZ). This agency, formerly known as TELARC, is governed by an act of Parliament. Generally laboratories with IANZ accreditation should be selected for analysis of samples because these laboratories will have quality assurance programmes in place to maintain analytical performance. Biosolids resource consents may specify that analytical measurements are to be carried out by an IANZ accredited laboratory. However, note that IANZ accreditation is test-specific and therefore not all IANZ laboratories may be accredited for the particular test you wish to use. Confirm the status of the test (i.e. analyte *and* method) accreditation with the laboratory *before* sending samples for analysis.

There are a number of New Zealand laboratories that have accreditation for the analysis of metals and organic contaminants governed by these *Guidelines*. There may, however, be microbiological tests for which no laboratory has the specific accreditation. In this case you should choose a competent laboratory and discuss the selection of an appropriate standard test method.

2.7.2.10 STANDARD SAMPLING TEXTS

The most widely utilised text of standardised analytical procedures for wastewater and aqueous environmental samples is *Standard Methods for the Examination of Water and Wastewater* (APHA, 1998). This covers a wide range of parameters applicable to the majority of wastewater-related monitoring programmes.

The USEPA has developed a large number of standard analytical procedures, many of which parallel the APHA standard methods. The list of standard USEPA methods can be found on the website: <http://www.epa.gov/epahome/index/>. The USEPA also have a large number of standard methods for chemical monitoring, including the monitoring of solids and sludges such as biosolids. These are primarily found in *SW-846 Test Methods for Evaluating Solid Waste*, which is available on-line at <http://www.epa.gov/epaoswer/hazwaste/test/main.htm>.

International and country-specific standards (including ISO and Standards New Zealand) are also available, which cover procedures and methods for sample collection and analysis for many of the parameters covered in these *Guidelines*.

2.7.2.11 AUDITING

Any sample programme should be audited, no matter how well prepared, in order to ensure that samples are being collected, transported and analysed correctly. If any problems are identified they should be resolved immediately to prevent the reporting of erroneous results.

To audit *sampling procedures*, a chain of custody form should be used throughout the sampling process. This should record the following information:

- name and signature of person collecting sample;
- date and time sample collected;
- purpose of the sample;
- analysis required;
- location of sample point and unique reference number (if one has been assigned);
- sampling method (i.e. grab or composite);
- preservation method;
- name of person receiving the sample for analysis;
- date analysed; and
- results, and whether these have been confirmed.

The general rule is to collect as much information as possible. This includes recording times, dates and results from any sample blanks taken. On-site sampling operation audits should also be conducted to ensure that samples are being taken correctly.

Analytical procedures will be assessed as part of a laboratory's quality assurance programme for obtaining and maintaining their laboratory accreditation.

2.7.2.12 DATA REPORTING

Analytical laboratories should provide reports that are complete, accurate and unambiguous so that clear conclusions can be drawn from the data without the need to make any assumptions. Laboratories must also maintain full records of samples, methodology and experimental data so that auditing can be carried out at any time to verify the reported results.

As a minimum, analytical reports should contain the following:

- sample identification and description;
- date of receipt of the sample and conditions of storage;
- date extraction of the sample commenced;
- details of the sample preparation and fraction of sample analysis;
- citation and summary of analytical procedure – it may be just the title for a validated regulatory method. Any modifications to the protocol should be noted; and
- date of reporting and signature of laboratory manager or other authorised signatory.

Results of analyses should be reported using the following conventions. Those for concentrations in the region of the detection limit follow recent trends in North America, which leaves any censoring data to the client but provide guidance on the quality of the data.

- No results are to be reported for analyses that were outside the calibration range of the instrument. Dilutions must be made to bring extracts/digests into the linear range.
- Concentrations of analytes in biosolids or soils should be presented on an oven dry (105°C) basis, with the moisture contents of the samples presented separately if requested.
- Analyte concentrations should be corrected for the blank and for recovery.
- Use SI units e.g. mg/kg, µg/kg rather than parts-per-million (ppm) or parts-per-billion (ppb).
- If there is no observed signal for the analyte, report as ND (not detected) at the quoted Method Detection Limit (MDL).
- If the analyte signal is detectable but the concentration is less than the MDL, report the concentration but flag as < MDL and in a region of uncertainty. Terms such as “trace” should be avoided.
- If the analyte concentration is greater than MDL, report unflagged.
- Separate results should be presented for each field replicate.
- The MDL and analyte recovery (% from spikes) should be given based on actual quality control (QC) samples run with the field samples and should not be estimates from previous method validation experiments. MDLs should be based on environmental control samples rather than laboratory blanks. If suitable control samples are not available, MDLs should be set on a conservative basis after a careful study of signals from field samples and blank samples.
- Results for laboratory replicates should be averages and marked in the report with the number of measurements; e.g. 0.31 mg/kg (3). Sets of laboratory replicate data should be summarised in the form of coincidence intervals to show within-laboratory precision.
- The mean and standard deviation of the recoveries for the surrogate analyte(s) across all samples should be reported.
- Results for all QC analyses (including laboratory blanks, field control samples, fortified laboratory matrix samples) run with client samples should be reported with ranges, means and confidence intervals where appropriate.

2.7.2.13 ASSESSMENT OF SAMPLE RESULTS

Results from the analysis of biosolids for chemical contaminants, reported on a dry weight basis, must meet the criteria given to ensure compliance with the requirements of these *Guidelines*, and for the biosolids to be beneficially used. In assessing compliance, the concentration measured for a contaminant, may exceed the limit given, providing that:

- the 95th percentile of the previous monitoring results (up to 24 months) for that contaminant are below the criteria
- the concentration does not exceed 20% of the limit value for that contaminant.

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3 THE REGULATORY FRAMEWORK

This section summarises the New Zealand regulatory framework and applicable legislation as at 2017

3.1 INTRODUCTION

The primary legislation governing the application of organic material products to land in New Zealand is the Resource Management Act 1991 (RMA). Other legislation (e.g., the Agricultural Compounds and Veterinary Medicines Act, the Health Act, the Land Transport Act) may have a direct or indirect bearing on a given manufacturing or distribution project depending on the project.⁵

This section of the Technical Manual outlines the relevant provisions of the key statutes relating to biosolids and other organic material management in New Zealand, with particular emphasis on the provisions of the RMA. It also provides guidance to regional councils on the nature and content of the rules that may be applicable to the regulation of such discharges to land in their region.

3.2 RESOURCE MANAGEMENT ACT 1991⁶

The discharge of contaminants (and hence many organic materials) to land in New Zealand is controlled by regional councils under the provisions of the RMA.

The purpose of the RMA is to promote the sustainable management of natural and physical resources, which include land, water, plants and animals. 'Sustainable management' is defined in terms of sustaining the potential of natural and physical resources to meet the reasonably foreseeable needs of future generations; safeguarding the life-supporting capacity of water, soil and ecosystems; and avoiding, remedying or mitigating any adverse effects of activities on the environment.

The Act focuses on the *effects* of activities rather than the activities themselves. Effects are defined to include both positive and adverse effects, and any cumulative effect that arises over time or in combination with other effects.

Discharges to land are controlled by section 15 of the RMA. If any contaminant in a discharge may enter water, or if the contaminants are from industrial or trade premises, then the person responsible for the discharge must obtain a resource consent, or must act in accordance with a rule in a regional plan or with regulations promulgated by central government.

3.2.1 RESOURCE MANAGEMENT OBJECTIVES AND POLICIES

Regional policy statements contain objectives and policies that promote the integrated management of the natural and physical resources of the region.

⁵ This *Guide* does not purport to contain definitive legal advice. If there is any doubt about legal issues surrounding a specific project, seek legal advice.

⁶ This section paraphrases the requirements of the RMA; if the need arises, or if in doubt, readers should refer to the full text of the relevant sections of the Act.

The objectives and policies of regional policy statements and regional plans prepared under the RMA are important because they establish the local decision-making framework, and in determining consent applications consent authorities (in this case regional councils and the Environment Court) are required to have regard to relevant objectives or policies of the regional policy statement, regional plans or proposed plans.

The RMA requires that councils adopt all provisions in their policy statements and plans in consultation with the community. Objectives state the resource management outcomes that councils and their communities are endeavouring to achieve. Policies provide the direction for *how* the objective is to be achieved. For example, in achieving the sustainable management of a regions' soil and water resources, a policy could be adopted that promotes practices such as reusing and recycling materials.

Encouraging the treatment of organic materials to a sufficient quality that allows it to be used as a soil conditioner and fertiliser will reduce environmental effects at landfills, improve soil quality and, if properly managed, recognise Maori culture and traditions. This helps promote the sustainable management of natural resources in New Zealand, while working towards achieving the zero waste objective of many councils.

3.2.2 REGIONAL RULES

Rules are key components of resource management plans, because once plans are approved they have the force of regulations. Regional councils can include rules in regional plans declaring the discharge of (specified or unspecified) organic materials to be a permitted activity, a controlled activity, a discretionary activity, a non-complying activity or a prohibited activity.

If the discharge is a *permitted activity* it is allowed without the need for a resource consent, providing it complies in all respects with any conditions specified in the rule.

If the discharge is a *controlled activity* it needs a consent and it has to comply with any standards or terms specified in the plan. A consent application is assessed in accordance with the matters council has reserved control over in the plan, and consent cannot be declined provided the activity complies with the standards and terms specified in the rule.

If the discharge is a *discretionary activity* it is allowed only if a resource consent is obtained and the consent authority can decline the consent application. The consent authority has full discretion in respect of the conditions it attaches to the consent.

3.3 AGRICULTURAL COMPOUNDS AND VETERINARY MEDICINES ACT 1997

The Agricultural Compounds and Veterinary Medicines (ACVM) Act 1997,⁷ administered by the New Zealand Ministry for Primary Industries, is narrowly focused on the application of substances (agricultural compounds) to agricultural land. The Act does not cover environmental effects or human health effects other than those in respect of food residues.

The purpose of the Act is to:

Prevent or manage risks associated with the use of agricultural compounds, being:

⁷ The ACVM Act replaced the previous Fertiliser Acts 1960, 1982; the Stock Foods Act 1946; and the Animal Remedies Act 1967.

- ◆ *Risks to trade in primary produce, and*
- ◆ *Risks to animal welfare, and*
- ◆ *Risks to agricultural security*
- ◆ *Ensure that the use of agricultural compounds does not result in breaches of domestic food residue standards*
- ◆ *Ensure the provision of sufficient consumer information about appropriate compounds.*

The ACVM Act provides that no person may *sell* or *use* any agricultural compound within New Zealand unless that agricultural compound is a registered 'trade name product' or is exempt by regulations made under section 75 of the Act.

Biosolids and manures fall within the definition of 'agricultural compounds' in the ACVM Act. There are some ambiguities in the wording of the ACVM Act and regulations and for interpretation the primary issue is the purpose of the material. To be considered an agricultural compound, a compound must be used (or expressly intended to be used) for the management of plants and animals in one or more of the ways listed in the ACVM Act definition.

3.4 HAZARDOUS SUBSTANCES AND NEW ORGANISMS ACT 1996

The Hazardous Substances and New Organisms (HSNO) Act provides comprehensive regulatory coverage of everything to do with hazardous substances management in New Zealand, including their import, manufacture, storage, transport, use and disposal. The HSNO Act, section 25, prohibits the import or manufacture of a hazardous substance other than in accordance with an approval under Part V of the Act.

The Act only covers substances that are hazardous. 'Substances' are defined in the Act to include:

(a) any element, defined mixture of elements, compound or defined mixture of compounds, either naturally occurring or produced synthetically, or any mixture thereof ... etc

It is clear that biosolids, manures or their constituents are substances. However biosolids, manures or their constituents are unlikely to trigger any of the hazardous property criteria. If this is the case, there would be no need for producers to obtain approval for use of their products under the HSNO Act.

3.5 HEALTH ACT 1956

The Health Act 1956 defines the functions and powers of the Medical Officer of Health who has an oversight role of the actions of the local authority. A duty of the local authority with respect to organic materials management is to ensure that the manufacture, distribution or use of these materials does not create a 'nuisance' (in terms of the definition in section 29 of the Health Act), and that these activities are not injurious to health. The Medical Officer of Health can take action if the local authority is not adequately protecting public health.

The Medical Officer of Health currently does not have any statutory approvals in relation to the discharge of organic materials to land.

3.6 HEALTH AND SAFETY AT WORK ACT (HSWA) 2015

This Act requires employers to protect the health and safety of employees in the workplace. It therefore applies to all organic material product producers, distributors, dischargers, and the owners of land to which these materials are applied.

WorkSafe New Zealand is the work health and safety regulator and administers the Act. WorkSafe recognises adherence with certain codes of practice as satisfying the requirements of the Act.

3.7 LAND TRANSPORT ACT 1998

The NZ Transport Agency (NZTA) manages the transport of goods on public roads in New Zealand under the provisions of the Land Transport Act 1998. The Agency makes and administers land transport rules, including a rule governing the transport of dangerous goods (Land Transport Rule No. 45001: Dangerous Goods 2005).

The Dangerous Goods Rule contains some basic safety requirements relating to secure containment, proper labelling, etc., but the Rule also requires compliance with *NZS 5433:1999 Transportation of Dangerous Goods on Land*, which contains detailed technical standards for labelling, loading, placarding, segregation, containerisation and documentation.

The Rule covers 'infectious material'. Under the grading scheme in this *Guide*, Grade A products (being essentially free of pathogens) would not be classified as 'infectious' whereas Grade B products (being organic materials with a potentially significant pathogen content) would be. That is, the transport of Grade B products would be subject to the Dangerous Goods Rule and NZS 5433.

Under the Rule, the onus is on the owner of the infectious material to advise the cartage contractor of the relevant regulatory requirements, and the contractor must be licensed to carry infectious goods. The cartage contractor or employee needs to have a correctly detailed Safety Data Sheet⁸ (SDS), plus his/her licence must be endorsed for Class D and the vehicle must be correctly registered. The penalty for non-compliance can be severe, with both the owner of the material and the cartage contractor being potentially liable for fines in excess of \$200,000. The rule is enforced by the police and local authority dangerous goods inspectors.

Territorial local authorities and Transit NZ have the capacity to make bylaws controlling the transport of hazardous substances on roads.

⁸ An example SDS is included in Volume 1, Appendix I.

4 PATHOGENS REVIEW

This section is available as two separate reports:

CIBR Publication 010 Pathogens Review January 2015 which is also available as a separate download [here](#). This document:

- ◆ Summarises existing knowledge on potentially pathogenic organisms in organic wastes;
- ◆ Reviews the justification for the inclusions of selected pathogens; and
- ◆ Reviews the recommended detection methods.

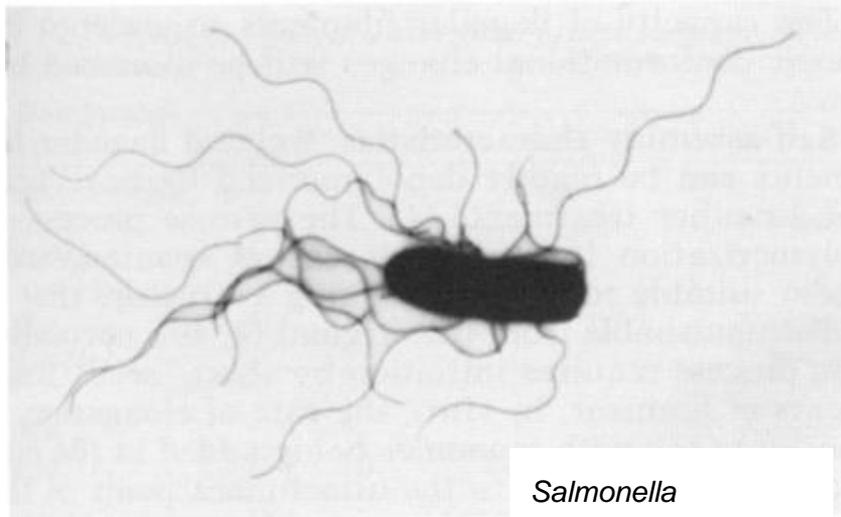
4.1 CIBR PUBLICATION 010 PATHOGENS REVIEW JANUARY 2015

4.2 ESR LETTER DATED 24TH JULY 2017

Following public consultation of the first public draft documents a subsequent review of selected queries was provided by Dr Jacqui Horsewell, ESR which is available as a separate download [here](#). The letter report responded to: “Could the stock exclusion of 6 months be reduced to 30 days?”



Centre for Integrated Biowaste Research



Organic Materials Guidelines - Pathogens Review

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EXECUTIVE SUMMARY

Unlike many other waste streams, there are good prospects for alternative, beneficial end-use options for organic wastes because they can be carbon-rich and contain high concentrations of valuable nutrients. However, because organic wastes can contain potentially pathogenic microorganisms their beneficial reuse requires management and regulation to ensure minimal environmental/public health risks and maximum value.

This report provides a review of current research findings and management experiences with respect to the occurrence and fate of potentially pathogenic organisms in organic wastes. It reviews the protection of public and environmental health provided by the *Ministry for the Environment, New Zealand Water and Wastewater Association (2003) Guidelines for the Safe Application of Biosolids to Land in New Zealand* and regulations/guidelines on animal wastes, and gives recommendations for improvements where appropriate.

The key findings of the review are listed below:

- The reliability of waste treatment processes in reducing pathogens is essential for public health protection. This is especially true for products that will be sold and/or handled by the general public. Pathogen reduction requirements for such products (e.g. Grade A products) should be performance based as opposed to process based and be required to prove pathogen destruction performance. Flexibility to allow alternative treatment processes to be used should be retained provided that it can be demonstrated through process verification and routine monitoring that any proposed treatment method meets an equivalent pathogen standard. Performance testing should also involve measurement of the microbial indicator in the waste before treatment, and in the final product, to determine the capacity of the treatment to reduce pathogens.
- There is no justification to reduce the number of microbial indicators currently required for verification testing to produce wastes that will be directly sold and/or handled by the public (e.g. Grade A products), except for helminths. Limits should reflect most up to date analytical detection limits. Research findings from the Sydney Water QMRA study indicate that the test methods for *Cryptosporidium* are still not sufficiently reliable to determine infectivity, thus it is recommended that, at this stage, *Cryptosporidium* is not included in any new guideline. For helminths, Sydney Water do not view these pathogens as a significant risk – it should be noted however that Australian risk assessments are based on human health in most cases and it is recommended that in New Zealand the Steering Group members should take direction from MPI on inclusion/exclusion of the helminth in any new guideline. It would also be useful to undertake a survey to determine how prevalent helminth ova are in New Zealand biosolids and other organic wastes. The key contact at MPI will be Emil Murphy in the Animal products team.
- It is recognised that substantial regrowth of pathogenic microorganisms can occur in treated organic wastes (especially biosolids), pathogen regrowth testing should

be conducted annually, using three samples for all products that may be directly sold and/or handled by the public.

- There is some justification to reduce the number of samples required for verification sampling for products that may be directly sold and/or handled by the public (i.e. Grade A products), from 15 to 7 grab samples as per the *Western Australian guidelines for biosolids management (2012)*.
- Due to their prevalence and concentration in sewage and sewage sludge, potential viral indicator candidates are human enteroviruses and human adenoviruses. The suitability of F-RNA and/or somatic bacteriophages (coliphages) as indicators in this context is still largely unknown. As human pathogens, the use of human enteroviruses or human adenoviruses is more informative than the use of bacteriophages. It is recommended that human adenovirus is measured as the virus indicator and that the methodology in the current *Guidelines for the Safe Application of Biosolids to Land in New Zealand (2003)* be modified. Although molecular analyses do not report on viability, qPCR could be useful for end product verification of Grade A composted biosolids, where the objective is to verify that viruses are removed. The Sydney Water QMRA supports the selection of human adenoviruses as the viral indicator in organic materials and also the integrated culture-PCR (C-PCR) methodology. The preliminary data from the QMRA indicate that human adenoviruses carry the greatest risk to human health, thus inclusion of human adenovirus in any new guideline is fully justified.
- There is no justification for increasing product monitoring requirements for organic wastes that are not directly sold and/or handled by the public (e.g. Grade B products). Management controls in the current *Guidelines for the Safe Application of Biosolids to Land in New Zealand (2003)* provide sufficient public and environmental health protection. However, before lifting site restrictions soil testing should be carried out to ensure that there has been no cumulative increase in microorganisms due to waste application. *Escherichia coli* is recommended for soil monitoring as it is neither arduous nor expensive, and may provide useful information on pathogen die-off in receiving soils.
- Agricultural wastes such as animal manures can potentially contain pathogens, the types of which are similar to those found in human sludge. There appear to be limited safeguards to protect public and animal health from potential pathogens in land applied animal wastes, risks are reduced by “good husbandry and management practices”. It is recommended that as for biosolids, these wastes undergo some form of process to reduce pathogens so that they do not pose a threat to public health and the environment.

INTRODUCTION AND CONTEXT

Purpose

The purpose of this report is to:

1. Summarise existing knowledge on potentially pathogenic organisms in organic wastes relative to the current *Guidelines for the Safe Application of Biosolids to Land in New Zealand (2003)* (Table 4.2).
2. In consultation with the Ministry of Health, Ministry for Primary Industries and Massey University, review the justification for the inclusion of the following pathogens: *E. coli*, *Campylobacter*; *Salmonella*; enteric viruses; helminth ova, which are in the current Biosolids Guidelines and to:
 - a. Provide recommendations about which pathogens should and should not be in a new guideline, including supporting logic.
 - b. Determine if other organic wastes contain additional pathogens of concern that should be included in a new guideline.
3. Review the recommended detection methods for pathogens in biosolids (Appendices 1 and 2 of the *Guidelines for the Safe Application of Biosolids to Land in New Zealand (2003)*); and provide recommendations for new methods for organic wastes with supporting logic.

Background

Organic wastes comprise more than 50% of the total wastes going to landfill in New Zealand. These wastes produce high greenhouse gas emissions and leach contaminants, including high levels of nitrogen. Unlike many other waste streams, there are good prospects for alternative, beneficial end-use options for organic wastes because they can be carbon-rich and contain high concentrations of valuable nutrients that can be used to bolster soil nutrient reserves, thereby reducing dependence on artificial fertilisers.

However, organic wastes can contain potentially pathogenic microorganisms that originate from tissues of diseased animals and people, and from healthy carriers who excrete infectious pathogens in faeces and urine. Many of these pathogens are zoonotic, i.e. they may cause infections in both animals and people and readily transfer between animals and human hosts. The biosecurity risk associated with the land application of organic wastes as fertilisers is hard to assess, and management requires technical guidance and regulation to ensure minimal environmental/public health risk and maximum re-use value.

The range of pathogenic microorganisms that may be found in organic waste streams derived from faecal material has been widely discussed in the literature; and in various reviews carried out in New Zealand and Australia, (e.g. 'Evaluation of the Contemporary Guidelines and Practices of Pathogen Identification, Screening and Treatment in Sewage Sludge to obtain Biosolids Products which are safe for Land Application in Western Australia' UWA, 2012; 'Pathogen Monitoring in Land Treatment Systems' Horswell, J. and Aislabie, J. 2006; ANZBP 'Pathogen Presence & Pathways Report' Ang, R. 2013).

Pathogens include species of bacteria, viruses, parasites, protozoa, helminths and fungi. The most important pathogens in terms of human health risk assessments are those spread by the faecal-oral route and include organisms such as *Campylobacter* spp., *Salmonella* spp., *Cryptosporidium*, *Giardia*, and enteric viruses. Pathogens of concern will also vary depending on geographical location, for example New Zealand has the highest rate of campylobacteriosis in the developed world, and thus *Campylobacter* spp. are a priority pathogen in New Zealand.

Over the last decade, at least one new pathogen per year that can be transmitted through the environment has been recognized as a public health threat (WHO, 2003). In addition, there are emerging, re-emerging or newly discovered pathogenic microorganisms for which there are typically few data available about their transmission routes, virulence, minimum infective dose, survival outside of host, or disinfectant susceptibility. Thus, there is a constant need to review current literature and update information for waste managers and regulators on risks and hazards from microbial contaminants that could potentially be present in organic wastes. This type of information will allow rapid response to any potential problem soon after it develops, when it is most easily dealt with.

Land application of most organic wastes requires a resource consent under the Resource Management Act (1991) in order to “*avoid, remedy or mitigate any adverse effects of activities on the environment*”.

The most comprehensive body of research has been undertaken on human wastes (biosolids). Through this research, strict guidelines and regulations are in place in many countries including Australia (e.g. NSW EPA, 1998), the United States (US EPA Part 503 Rule, 1993) and New Zealand (NZWWA, 2003). These guidelines recommend appropriate treatment processes to reduce pathogen levels as well as practices for the safe handling, storage and application of biosolids. Thus, for the purposes of this report we mainly focus on biosolids guidelines, which serve as a model for management of organic material for beneficial reuse.

Resources used

The most comprehensive regulation on biosolids is US EPA Part 503 Rule (1993). Development of the Australia/New Zealand guidelines has been strongly based on this US EPA guideline. For the purposes of this review we have primarily used the following resources:

- US EPA; US Environmental Protection Agency (1993) Part 503-Standards for the Use or Disposal of Sewage Sludge. Federal Register 58, 9387-9404.
- Australian and New Zealand Biosolids Partnership (ANZBP): Review of Biosolids Guidelines (2009). Paul Darvodelsky, Dominic Flanagan, Jim Bradley
- Western Australian guidelines for biosolids management (2012) Department of Environment and Conservation
- EU policy on sewage sludge utilization and perspectives on new approaches of sludge management. (2014). G. Mininni & A. R. Blanch & F. Lucena & S. Berselli, Environmental Science and Pollution Research. Online.

- A Quantitative microbial risk assessment (QMRA) study undertaken by Sydney Water.

Rationale for developing waste management guidelines

One of the key drivers for the development of guidelines for waste management is to protect public health.

Most guidelines around the world have the same basic structure and are made up of four parts. Together they combine to give the desired level of protection for the community and environment.

1. Contaminant controls
2. Pathogen and vector attraction reduction
3. Management controls
4. Sampling and monitoring

BASIC STRUCTURE OF INTERNATIONAL GUIDELINES

1. Contaminant controls

Directly refers to inorganic and organic contaminants and is dealt with by another Working Group report.

2. Pathogen and vector attraction reduction

In most guidelines regulation of pathogens is carried out in two ways. The first is on the basis of the performance of known processes; and the second is to reduce pathogens to the numerical standards set out in the guidelines.

Rationale for Processes Control

The reliability of sludge treatment processes in reducing pathogens is essential for public health protection.

Most guidelines (including those in Australia, New Zealand and the United States) list approved or specified treatment technologies that are known to reliably and consistently reduce pathogens (e.g. lime treatment, aerobic thermophilic digestion, anaerobic digestion, composting). Most guidelines also provide some degree of flexibility and allow alternative biosolids treatment processes to be used provided that it can be demonstrated through process verification and routine monitoring that proposed treatment method meets an equivalent pathogen standard.

Rationale for requirement for both process control and pathogen monitoring

A key finding of the Australian and New Zealand Biosolids Partnership: Review of Biosolids Guidelines (2009) was that:

“Pathogen reduction requirements should be performance based as opposed to process based.....”, and that “The requirement to prove pathogen destruction performance of unknown processes should be retained”.

This approach is important to ensure that the microbiological reductions expected as a result of the treatment process (e.g. time, temperature) have actually been attained. The performance testing generally uses final product evidence for quality control: low level *E. coli* and non-detect *salmonella*, helminth and enteric viruses as indicators of destruction of pathogenic organisms.

The importance of ‘performance testing’ is further explained in an email from the author of the ANZBP: Review of Biosolids Guidelines (2009), Paul Darvodelsky, on the 21st July 2014.

“We also believe that there should be the facility to demonstrate a new process can meet a certain level of pathogen kill and hence be acceptable. I would expect in a guideline that it would have the following form:

1. *Proven processes which are accepted as reaching a certain standard. Regular testing required to demonstrate that the process is operating properly;*
2. *New processes which can be proven to reach a certain standard which would then require regular testing to demonstrate the process is operating properly. I would expect such a process would also have to demonstrate a mechanism by which it achieved pathogen kill, i.e. no magic processes; and*
3. *Processes which don't fall into either category (e.g. vermiculture) which would require testing for every batch to prove the product meets the standard claimed. This testing would be the same as process verification and regular monitoring analyses, as sensible, to ensure product quality."*

In the current *Guidelines for the Safe Application of Biosolids to Land in New Zealand* (2003) the performance of a process is determined via verification sampling:

"Verification sampling is required to demonstrate that a treatment process is producing a final product of consistent quality. This phase of monitoring is typified by a high-frequency sampling regime. Verification monitoring should occur not only when a new process is commissioned but also when changes are made to an existing process, and also if any of the routine samples exceed the limits set for pathogens or chemical contaminants; in other words, whenever there could be a possible change to the quality of the final product."

Below is Table 6.2: *Pathogen standards* which outlines the criteria for verification sampling and routine sampling for biosolids to meet *Grade A* from the *Guidelines for the Safe Application of Biosolids to Land in New Zealand* (2003).

Table 6.2: Pathogen standards¹

Pathogen	Verification sampling	Routine sampling
<i>E. coli</i>	< 100 MPN ² /g	< 100 MPN/g
<i>Campylobacter</i>	< 1/25 g	N/A ⁴
<i>Salmonella</i>	< 1/25 g	N/A
Enteric viruses	< 1 PFU ³ /4g	N/A
Helminth ova	< 1/4g	N/A

(Source: *Guidelines for the Safe Application of Biosolids to Land in New Zealand* (2003))

Discussions with the NZ Ministry of Health, Paul Prendergast and John Harding on the 10th of June 2014, indicated a preference for more of a focus on 'process' rather than sampling and monitoring (i.e. performance testing or the verification testing that is currently in the guidelines).

A key difference between the *Guidelines for the Safe Application of Biosolids to Land in New Zealand* (2003) and the US EPA Part 503 rule (1993) is the US EPA rule requirement to measure the microbial indicators both in the sludge during the treatment train, and in the final biosolids, to determine the capacity of the treatment to reduce pathogens. The US EPA Part 503 (1993) provides justification for this:

“Testing for enteric virus and viable helminth ova can be complicated by the fact that they are sometimes not present in the untreated sludge. In this case an absence of the organisms in the treated sludge does not demonstrate that the process can reduce them to below detectable limits. Monitoring should be continued until enteric viruses and/or viable helminth ova are detected in the fed sewage sludge. The treated sewage can then be analysed to determine if these organisms survived treatment. Thus it is essential to validate the treatment process until adequate specified pathogens reduction has been successfully demonstrated”

The Western Australian guidelines for biosolids management (2012) also state that:

“Treatment performance involves measurement of the microbial indicator in the sludge during the treatment train, and in the final biosolids, to determine the capacity of the treatment to reduce pathogens. The calculation of pathogen log removals, following treatment with a quality assurance/quality control program, is considered a better approach for microbial risk management rather than only end-point quality monitoring for microbial indicators.”

However the Western Australian guideline also recognises that:

“At present, only end product quality is includedbecause there are insufficient data to determine the log removals that can be achieved for each one of the approved treatment methods. However, projects are required to monitor for microbial treatment performance.”

In the *Guidelines for the Safe Application of Biosolids to Land in New Zealand* (2003) there is currently no requirement to demonstrate removal of microbial indicators by measuring them before and after treatment.

Recommendation

It is recommended that microbial indicators in the organic waste are measured during the treatment train, and that verification monitoring must be carried out until all microbial indicators are detected in the fed waste to prove the process can effectively remove them.

Most international guidelines, including the *Guidelines for the Safe Application of Biosolids to Land in New Zealand* (2003) allow for ‘flexibility’ of treatment process to allow for new technologies. If biosolids are produced using different methods than those listed in the guideline, it must be demonstrated through process verification and routine monitoring that any proposed treatment method meets an equivalent pathogen standard. In the

Guidelines for the Safe Application of Biosolids to Land in New Zealand (2003), Table 6.1: Stabilisation requirements it states that “other processes” must show:

“Demonstration by agreed comprehensive process and product monitoring that the Grade A pathogen levels can be consistently met.”

The US EPA Part 503 rule (1993) also allows such flexibility as show in Table 5-1 below.

TABLE 5-1
Summary of the Six Alternatives for Meeting
Class A Pathogen Requirements

In addition to meeting the requirements in one of the six alternatives listed below, the requirements in Table 5-2 must be met for all six Class A alternatives.

Alternative 1: Thermally Treated Biosolids

Biosolids must be subjected to one of four time-temperature regimes.

Alternative 2: Biosolids Treated in a High pH-High Temperature Process

Biosolids must meet specific pH, temperature, and air-drying requirements.

Alternative 3: Biosolids Treated in Other Processes

Demonstrate that the process can reduce enteric viruses and viable helminth ova. Maintain operating conditions used in the demonstration after pathogen reduction demonstration is completed.

Alternative 4: Biosolids Treated in Unknown Processes

Biosolids must be tested for pathogens—*Salmonella* sp. or fecal coliform bacteria, enteric viruses, and viable helminth ova—at the time the biosolids are used or disposed, or, in certain situations, prepared for use or disposal.

Alternative 5: Biosolids Treated in a PFRP

Biosolids must be treated in one of the Processes to Further Reduce Pathogens (PFRP) (see Table 5-4).

Alternative 6: Biosolids Treated in a Process Equivalent to a PFRP

Biosolids must be treated in a process equivalent to one of the PFRPs, as determined by the permitting authority.

(Source: US EPA; US Environmental Protection Agency (1993) Part 503-Standards for the Use or Disposal of Sewage Sludge. Federal Register 58, 9387-9404.)

As noted above by Paul Darvodelsky in the email communication on 21st of July 2014, for some processes, verification or performance testing alone may not be adequate to ensure human health protection.

“Processes which don’t fall into either category (e.g. vermiculture) which would require testing for every batch to prove the product meets the standard claimed. This testing

would be the same as process verification and regular monitoring analyses, as sensible, to ensure product quality.”

Recommendation

It is recommended that for processes that could potentially produce an inconsistent product, due to difficulties in controlling the process, every batch should be tested for the full range of microbial indicator organisms. Such processes would include vermicomposting where it is difficult to control the biological process to the same extent as traditional composting (where time and temperature can be more easily controlled).

Rationale for testing for pathogen re-growth potential

It is recognised that substantial regrowth of pathogenic bacteria in treated biosolids (even Class A) can occur (US EPA, 1993, Western Australian guidelines for biosolids management, 2012). However a key difference between the *Guidelines for the Safe and Application of Biosolids to Land in New Zealand* (2003), and the US EPA Part 503 rule (1993) and the *Western Australian guidelines for biosolids management* (2012) is their approach to testing of biosolids for re-growth potential, with the *Western Australian guidelines for biosolids management* (2012) taking a more cautious view.

Whilst the *Guidelines for the Safe Application of Biosolids to Land in New Zealand* (2003), recognises that:

“Ideally, monitoring the quality of biosolids should occur just prior to their use. This practice is in accordance with the USEPA, European Union, NSW EPA and the NRMCC guidelines. When determining the stabilisation grade, pathogen reduction monitoring should only be undertaken on the final product (just before sale), because pathogenic organisms may regrow after treatment has taken place”.

The US EPA Rule 503 (1993) considers that biosolids should be tested at:

“...the last practical monitoring point before the biosolids is applied to the land or placed on a surface disposal site. Biosolids that are sold or given away cannot be monitored just prior to actual use or disposal; instead monitoring is required as it is prepared for sale or given away.”

The Western Australian guidelines for biosolids management (2012) takes this one step further by requiring annual testing of a product for re-growth:

“For biosolids or products containing biosolids of P1 and P2 grade, regrowth testing for E. coli and coliphages is required in order to demonstrate that the treatment process is working effectively and that, in combination with normal end-use management controls, re-growth has not occurred. Re-growth testing should be conducted annually, using three samples.”

In New Zealand anecdotal evidence suggests that there may be potential for significant pathogen re-growth in biosolids products that may be stockpiled before release. An

example of this is composted biosolids that may be stockpiled uncovered and therefore be able to be re-wetted by rainfall or reinoculated with pathogens by birds or vermin

Recommendation

It is recommended that pathogen re-growth testing be conducted annually, using three samples in all Grade A products.

Rationale for numerical standards (Pathogen Grading)

Most biosolids guidelines contain pathogen grading that is dependent upon meeting:

- a treatment process known to reliably reduce pathogen levels;
- microbiological limits that demonstrate the effectiveness of the treatment process; and
- a vector attraction reduction control.

Ideally, to determine the microbiological quality of biosolids, testing should be undertaken for all pathogens, but this is not currently practicable. Consequently, microbial indicators are still used for routine evaluation of treatment performance and final biosolids quality. Indicator organisms are organisms believed to indicate the presence of a larger set of pathogens. An indicator organism should ideally have the following characteristics:

- consistently present in relatively high numbers in waste streams;
- standard methods exist to easily isolate and identify; and
- behave in a similar way to pathogenic organisms (because their life processes and ecological niches are similar), in both sewage treatment process and after land application.

The ANZBP: Review of Biosolids Guidelines (2009) undertook a comparison of the current pathogen requirements for Australia, New Zealand, the UK, EU and USA; “*Table 5.8 Stabilisation grade comparison*”.

Table 5.8 – Stabilisation grade comparison

	NSW, Qld, ACT	National	SA	Tas	Vic	WA	NZ	UK Safe Sludge Matrix	EU	USA
E. coli (MPN/g)	<100	<100	<100	<100	<100	<100	<100	<1000 + 6 log reduction	-	no criteria
Faecal coliforms (MPN/g)	<1,000	<100	-	<100	-	-	N/A	no criteria	-	<1000
salmonella sp. (/50g)	nd	<1	<1	<1/100 g	-	<1	<1/25g	absent from 2 g DS	-	or <3 per 4g DS
Enteric viruses (PFU/4g ds)	-	-	<1/50 g ds	-	-	-			-	
Helminth ova (PFU/4g ds)	-	-	<1/50 g ds	-	-	1			-	
Campylobacter							<1/25g		-	

(Source: Darvodelsky, P., Flanagan, D. and Bradley, J. (2009). Summary of Australian and New Zealand Biosolids Partnership: Review of Biosolids Guidelines)

Summary of Pathogen Grading in Western Australian guidelines for biosolids management (2012) Department of Environment and Conservation

Four pathogen grades are used: P1, P2, P3 and P4 and the standards are shown in “Table 2: Approved treatment methods” of the Western Australian guidelines.

Escherichia coli (*E. coli*) and coliphages are considered suitable microbial indicators of faecally derived bacteria and viruses respectively.

The highest grade of biosolids treatment (P1, equivalent to Grade A in the *Guidelines for the Safe and Application of Biosolids to Land in New Zealand*, 2003), must meet coliphages <10 PFU/10 g of dry final biosolids AND *E. coli* less than 100 counts per g of dry final biosolids. Strongyloides and Hookworm (viable ova) <1 per 50 g of dry final biosolids (only required north of the 26th parallel).

E. coli

E. coli is a bacterium from the thermo-tolerant coliforms group. *E. coli* monitoring can be used alone for pathogen grade P2 and P3 applications (that is, biosolids applications with low likelihood of human contact) and are equivalent to Grade B in the *Guidelines for the Safe Application of Biosolids to Land in New Zealand* (2003).

Coliphages

Coliphages are viruses that infect coliform bacteria (including *E. coli*) and their inclusion is a new parameter for routine evaluation of treatment performance and final P1 biosolids quality. The guidelines note that:

“laboratories in WA are yet to validate analytical techniques and obtain NATA accreditation for this testing”.

There are many types of coliphages, usually one or both of two groups, somatic bacteriophages and F-RNA bacteriophages (e.g. MS2), are monitored. The somatic bacteriophages are usually more numerous in sludge and are more resistant to thermal inactivation than F-RNA bacteriophages. F-RNA bacteriophages are less prevalent in human faeces than somatic bacteriophages but they can be cultivated and enumerated to perform challenge tests to demonstrate the log removals a treatment can achieve.

Helminths

Helminths monitoring is only required for biosolids applications in endemic areas of WA (e.g. the Kimberley region). Specifically the guideline requires monitoring for Strongyloides and Hookworm with a viable ova limit of <1 per 50 grams of dry final biosolids.

The EU

Recycling sludge is a highly regulated activity in the EU. Current controls are based on the 1986 EU Sludge Directive (86/278/EEC). The sludge directive has no specific regulation and monitoring of microbial parameters to provide barriers on disease transmission. However, the transposition of the Directive in different member state legislation has led to some countries adopting additional health regulatory requirements on sludge treatment process and currently the international limit values on pathogens are placed in a rather wide range. This is the inevitable consequence of different attitudes towards sludge management practices in the member states.

The table below shows the standards for maximum concentrations of pathogens in sewage sludge in some EU countries (Mininni et al., 2014)

Table 1. Standards for maximum concentrations of pathogens in sewage sludge

	Salmonella	Other pathogens
Denmark (advanced treatment only)	No occurrence	Faecal streptococci, <100/g
France	8 MPN/10 g DM	Enterovirus, 3 MPCN/10 g DM Helminths eggs, 3/10 g DM
Finland	Not detected in 25 g	<i>Escherichia coli</i> <1,000 cfu
Italy	1,000 MPN/g DM	
Luxembourg		Enterobacteria, 100/g no eggs of worm likely to be contagious
Poland	Sludge cannot be used in agriculture	

	if it contains salmonella	
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(Source: EU policy on sewage sludge utilization and perspectives on new approaches of sludge management. (2014). G. Mininni & A. R. Blanch & F. Lucena & S. Berselli, Environmental Science and Pollution Research. Online.)

In a recent review undertaken by Mininni et al. (2014) the authors reference a sludge directive revision working document draft from European Commission “Working Document on Sludge, 3rd Draft, Brussels, 27 April 2000, ENV.E.3/LM”. This working document proposes that:

“...sludge to be used in agriculture without restrictions, should comply with the following requirement: being treated by advanced process, that fulfils the limits of E. coli <500 CFU/g and Salmonella <1/50 g and achieves 6 log reduction of a test organism such as Salmonella senftenberg”.

However it is also noted that the feasibility and reliability of spiking *Salmonella senftenberg* is still amply debated.

The European Commission “Working Document on Sludge, 3rd Draft, Brussels, 27 April 2000, ENV.E.3/LM” goes on to suggest conventional indicators (e.g. *Escherichia coli*, faecal coliform bacteria, clostridia, somatic coliphages, etc.) and/or index pathogen (*Salmonella*) are used as surrogates of pathogen presence for routine evaluation of treatment plant performance and sludge microbial quality. Bacterial indicators present limitations for their role as surrogates of parasites and viruses. In order to overcome such limitations, spores of *Clostridium perfringens* have been proposed as alternative indicators of protozoan cysts in water treatments while bacteriophages of enteric bacteria had been advocated as surrogates of waterborne viruses in water quality control process.

However, an EU funded project “The ROUTES project (www.eu-routes.org), “Novel processing routes for effective sewage sludge management” has found that *C. perfringens* should be abandoned as a microbial indicator as they are not good indicators of the performance of anaerobic processes.

Finally, the Mininni et al (2014) review notes that:

“It does not seem that a new sludge directive is pending. Works in progress have not evidenced a health and environment impact due to sludge agricultural use although some attention is already paid by many member states on organic pollutants and pathogens.”

UK

The EU Sludge Directive (86/278/EEC) was implemented in the UK in 1989 through *The Sludge (Use in Agriculture) Regulations*. The regulations are supported by *The Code of Practice for the Agricultural Use of Sewage Sludge* (1996), which details all aspects of sludge recycling to land; setting application rates, information requirements and guidelines for best practice.

It is anticipated revisions to the regulations and the accompanying Code of Practice will be introduced by the Department for Environment, Food and Rural Affairs (DEFRA) and will include statutory enhancement of *The Safe Sludge Matrix*. *The Safe Sludge Matrix* is currently a voluntary agreement between food retailers (British Retail Consortium) and UK water authorities and was developed to ensure the highest possible standards of food

safety and to provide a framework that gives all food industry stakeholders confidence that biosolids recycling to agricultural land is safe.

As a requirement of *The Safe Sludge Matrix*, sewage sludge is treated by processes to generate either conventional or enhanced biosolids products, which are suitable for recycling to agricultural land. Conventionally treated sludge has been subject to a defined treatment process and standards that ensure at least 99% of pathogens have been destroyed. Enhanced treated sludge will be free from *Salmonella* and will have been treated so as to ensure that 99.9999% pathogens have been destroyed (a 6 log reduction).

Summary of Pathogen Grading in US EPA Part 503 Rule (1993)

The 40 CFR Part 257 – *Criteria for classification of solid waste disposal facilities and practices* requires the use of specifically listed or approved treatment technologies to treat biosolids. Part 503 provides flexibility in how pathogen reduction and vector attraction reduction is met by giving 6 alternatives (“*Table 5-1 Summary of six alternatives for meeting Class A pathogen requirements*”) (page 9), and requires microbial indicator measurements to be undertaken as shown below in “*Table 5-2 Pathogen requirements for all Class A Alternatives*”.

**TABLE 5-2
Pathogen Requirements for All Class A Alternatives**

The following requirements must be met for *all* six Class A pathogen alternatives.

Either:

the density of fecal coliform in the biosolids must be less than 1,000 most probable numbers (MPN) per gram total solids (dry-weight basis),

or

the density of *Salmonella* sp. bacteria in the biosolids must be less than 3 MPN per 4 grams of total solids (dry-weight basis).

Either of these requirements must be met at one of the following times:

- when the biosolids are used or disposed;
- when the biosolids are prepared for sale or give-away in a bag or other container for land application; or
- when the biosolids or derived materials are prepared to meet the requirements for EQ biosolids (see Chapter 2).

Pathogen reduction must take place before or at the same time as vector attraction reduction, except when the pH adjustment, percent solids vector attraction, injection, or incorporation options are met.

(Source: US EPA; US Environmental Protection Agency (1993) Part 503-Standards for the Use or Disposal of Sewage Sludge. Federal Register 58, 9387-9404.)

If thermal treatment or high pH/temperature are used (alternatives 1 or 2, Table 5-1, page 9) then Part 503 requires monitoring for faecal coliforms and a density of less than 1,000 MPN faecal coliform per gram of total solid sewage sludge (dry weight basis) to be Class A. Part 503 also allows *Salmonella spp.* to be monitored instead of faecal coliforms. The density of the *Salmonella* must be below detection limits of 3 MPN/4 g of total sewage sludge solids (dry weight). The limit of 1,000 MPN faecal coliform is based on experimental evidence carried out by Yanko (1987) which demonstrated that this level of faecal coliform correlated with a very low level of *salmonellae* detection in composted sludge.

If alternatives 3 – 6 (in Table 5-1) (page 9) are used (other or unknown processes), then according to Table 5-2 the biosolids must also be monitored for enteric virus with a limit of less than the detection limits of 1 CFU/ 4 g; and 1 viable helminth ova /4g total solids.

Sydney Water Quantitative microbial risk assessment (QMRA)

Sydney Water is currently undertaking a Quantitative Microbial Risk Assessment (QMRA). A QMRA is a framework and approach that brings information and data together with mathematical models to address the spread of microbial agents through environmental exposures and to characterize the nature of the adverse outcomes. The Sydney Water QMRA has been monitoring pathogen reduction in four of their waste water treatment plants. The treatments include:

- Primary anaerobic digestion
- WAS anaerobic digestion
- WAS aerobic digestion
- Liquid sludge (lagoon for 6 months)

Twelve months (monthly interval) of pathogen data in both raw wastewater (influent) and biosolids have been measured in the most comprehensive risk assessment undertaken to date. The pathogens enumerated were: adenovirus (CC-PCR), Cryptosporidium (IFA/DAPI), Giardia (IFA/DAPI), Salmonella (MPN) and indicators, E. coli, faecal coliforms, and enterococci. Significant resources have been dedicated to development/improvement of pathogen detection methods including recovery data for the organisms in the complex media that is biosolids. At the time of writing this review, the raw data was being processed in the QMRA model. On the 21st of November, 2014, Jacqui Horswell met with representatives from Sydney Water to discuss the QMRA study and preliminary research findings.

Below is a brief summary of results to date:

- The QMRA model ranks exposure in the following order: treatment plant workers > farmers > consumers.
- The Technical Specialists at Sydney Water have selected human adenovirus as the most appropriate indicator of viruses in biosolids and use the CC-PCR method for detection. The preliminary data from the QMRA indicate that human adenoviruses carry the greatest risk to human health.
- The main driver for inclusion of Cryptosporidium in the QMRA was the detection in the Greater Metropolitan Sydney drinking water of Cryptosporidium in 1998.
- Sydney Water has developed an in-house method for enumeration of viable Cryptosporidium based on the infection of cells in tissue culture. This method is similar to other methods used internationally for this purpose. The standard DAPI staining indicates that the organism's nucleus is intact but this does not necessarily mean that the organism is infective. Sydney Water use the additional infectivity test with HCT8 cells and have determined that oocysts from natural surface waters generally have low infectivity (1 to 10%), unless recently contaminated with infected faecal material such as sewage effluent or farm runoff, and the upper limit seems to be ~35% in freshly shed oocysts. Discussion with Sydney Water Technical Specialists suggests that although the methodology has been significantly improved, there are still difficulties recovering organisms from complex media such as biosolids and viability testing is not straightforward. While it is expensive in itself to do the cell culture viability test, it is comparable in cost to the standard Cryptosporidium and Giardia

enumeration and may add considerable value where a risk assessment needs to clarify the true health risk. At present it is primarily a tool for research and major projects where it can add value. Sydney Water has on-going discussions with laboratories using similar methods in research to ensure clients and the industry in general get the best value from using the test and its results appropriately.

- Potentially infective *Cryptosporidium* has been detected in biosolids at low levels in the Sydney Water study. It should be noted that there was limited scope for testing infectivity by the cell culture infectivity test in the course of the study. While it is possible to detect a single infectious oocyst by this method, it was felt that results would be equivocal if less than 10 oocysts total could be inoculated into per test, both to allow quantitation of the inoculum and because in general only a minor fraction of oocysts are found to be infectious (see above). Fewer than hoped of the samples reached this criterion: only three samples were tested, and no infectious oocysts were detected in biosolids. In the opinion of the Sydney Water Technical Specialist only one treatment works (Picton aged sludge) was well enough examined to place an upper bound on infectivity (< 1.5% approx.).
- Monitoring of helminths is not seen as a priority by Sydney Water due to the low prevalence of helminths in the catchment area and also the end-use of the biosolids which is predominantly the agricultural sector. Sydney Water are currently developing an in-house detection method for helminths which may improve reliability of the data.
- Levels of *Salmonella* detected in the biosolids were low and not identified as a risk in the preliminary QMRA.

Recommendation

The drivers for organisms selected in the Sydney Water QMRA study may be different to New Zealand, this is likely the case for *Cryptosporidium* and helminths. It is recommended that monitoring of *Cryptosporidium* in Grade A biosolids is still not required due to continued difficulties with measurements for viability/infectivity. The preliminary QMRA results have provided justification for the continued inclusion of viral indicators in NZ guidelines.

Summary of New Zealand Guidelines

Two pathogen standards are used, A and B. Standards have been set for Grade 'A' for faecal coliforms, *salmonella spp.*, *campylobacter spp.*, enteric viruses and helminths and limits are shown in *Table 6.2: Pathogen standards* above (page 7).

Grade A biosolids are effectively "pathogen free" and microbiological criteria specified in various guidelines are based on detection limits for a particular pathogen, however there is some disagreement between guidelines on detection limits. Grade 'A' biosolids are considered to be of significantly high quality that they can be safely handled by the public and applied to land without significant risk of adverse effects.

Faecal indicators and pathogens in biosolids

E. coli

Many countries, including the USA, still use faecal coliforms in their regulations and guidelines. This is because they have large historical data sets based on faecal coliform levels in biosolids. The US is currently building up *E. coli* data bases and may switch to measuring *E. coli* in the future (pers com. J. E. Smith, US EPA). Current limits in the *Guidelines for the Safe Application of Biosolids to Land in New Zealand (2003)*, are based on US EPA Part 503 (1993) limit of < 1,000 MPN/g for faecal coliforms, the justification for this limit is based on work undertaken by Yanko (1987) who demonstrated that this level of coliforms correlated with low numbers of *salmonella*. In general *E. coli* levels are ten-fold lower than faecal coliforms, hence the current *E. coli* limit of < 100 MPN/g is set in the *Guidelines for the Safe Application of Biosolids to Land in New Zealand (2003)*.

It has been widely demonstrated that coliform bacteria do not adequately reflect the occurrence and survival of pathogens in treated sewage and wastewater (Harwood et al. 2005; Moce-Llivina et al. 2003, Sidu and Toze, 2009), and it is thus important to monitor a suite of organisms including a sub-set of pathogens, this is the case for most international guidelines including US EPA Part 503 and the Australian guidelines as shown in “*Table 5.8 Stabilisation grade comparison*” (above, page 12) taken from the ANZBP: *Review of Biosolids Guidelines* (2009).

Campylobacter

The *Guidelines for the Safe Application of Biosolids to Land in New Zealand (2003)*, are unique in requiring monitoring for *Campylobacter*. They state that:

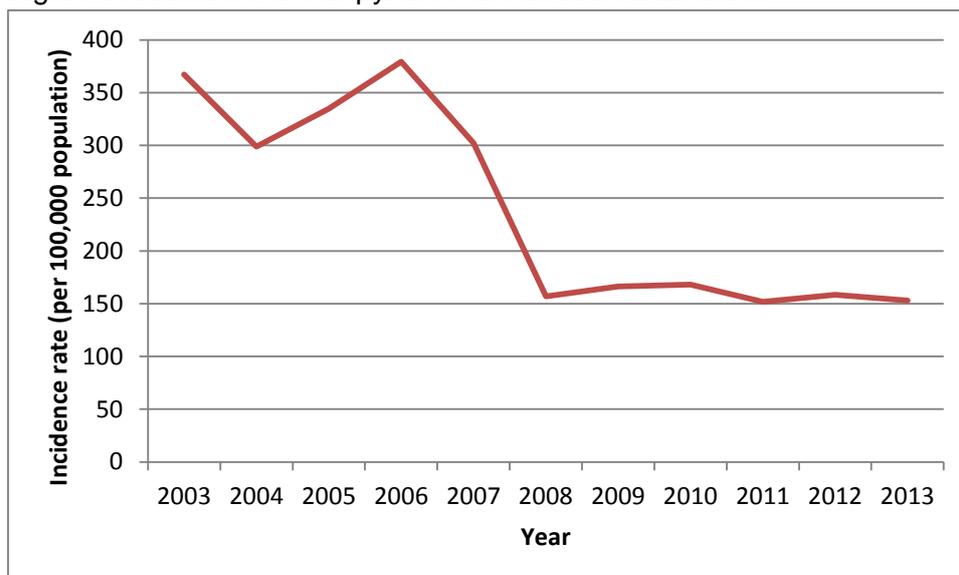
“Whereas Salmonella spp. are traditionally used as an indicator for pathogen removal, the high incidence of campylobacter infection in the New Zealand community makes it a greater risk. For this reason campylobacter is required for verification sampling.”

The incident rate of campylobacteriosis has declined since 2003. Figure 1 below shows the incidence of campylobacteriosis from 2003 – 2013 (New Zealand Public Health Surveillance Reports (NZPHS)). However, this rate is still significantly higher than the rest of the developed world (e.g. in Australia the rate is only 78 per 100,000 population (Notifiable Infectious Disease Reports, WA Department of Health, 16 June 2014)). Therefore, there is no justification for removing *Campylobacter* as a microbial indicator in a New Zealand guideline.

Recommendation

It is recommended that the Steering Group members take direction from the Ministry of Health on inclusion/exclusion of *Campylobacter* in any new guideline.

Figure 1. Incidence of campylobacteriosis in New Zealand



(Source: New Zealand Public Health Surveillance Reports (NZPHS))

Salmonella

Salmonella sp. are monitored as indicators of the impact of treatment processes on bacterial pathogens. They are an important human pathogen, with salmonellosis ranking 5th in a ranking of New Zealand notifiable diseases in 2013 (summarised from appendices to the 2013 ESR Public Health Surveillance report:

https://surv.esr.cri.nz/PDF_surveillance/AnnualRpt/AnnualSurv/2013/2013AnnualSurvTables.pdf)

The limits given in US EPA Part 503 (1993) rule for *Salmonella* spp. are 3 MPN/4 g which according to the guidelines, are the detection limit for *Salmonella* spp. The current limit in the *Guidelines for the Safe Application of Biosolids to Land in New Zealand (2003)* is based on the requirement of the Living Earth Joint Venture (LEJV) consent figure of 1/25g. At the time, this resource consent, to produce composted biosolids from Wellington sewage sludge, contained the most comprehensive microbial risk assessment information.

Discussions with Sunita Raju, Team leader for microbiology at Eurofins in Wellington, indicated that their detection limit for *Salmonella* spp. is <2 MPN /g (pers comm 21 July 2014).

Recommendation

It is recommended that the limit for *Salmonella* be reduced to the analytical detection limit for the MPN method for *Salmonella*; <2 MPN/g.

Enteric viruses

Human enteric viruses include many virus types/ groups including enteroviruses, adenoviruses, noroviruses (described in the current NZ guidelines and/ or by given in US EPA Part 503 (1993) rule, as small round structured viruses and/or Norwalk virus), astroviruses, sapoviruses and hepatitis A and E virus. Therefore a virus indicator or representative is required as it is not possible to detect all virus types using any one assay. When information on viability is required, there are only a few enteric virus candidates, due to difficulties with the culture of many of the enteric virus groups.

The current *Guidelines for the Safe Application of Biosolids to Land in New Zealand* (2003), refer to the quantification of enteric viruses with limits derived from the US EPA Part 503 (1993) rule of < 1 plaque forming unit (PFU) enteric viruses/4 g (dry solids). The methodology given in the current *Guidelines for the Safe Application of Biosolids to Land in New Zealand* (2003), is for human adenoviruses, the rationale being that human adenoviruses are generally more resistant to physical and chemical agents than other enteric viruses. For example, human adenoviruses have been shown to be more resistant to UV inactivation than enteroviruses (reviewed by Sidhu and Toze, 2009).

The US EPA specify the detection of enteroviruses as representative of enteric viruses, whilst the *Western Australian Guidelines for Biosolids Management* (2010) and the directive revision working document draft from European Commission (2000), specify the measurement of bacteriophages (coliphages) as possible indicators of enteric viruses due to their prevalence in human sewage and relative ease of culture (Pillai et al., 2011). A class I pathogen product must contain < 10 PFU/g (dry weight) of F-RNA or somatic bacteriophages in the WA guidelines.

What is the best viral indicator?

Due to their prevalence and concentration in human sewage, potential viral candidates are human enteroviruses and human adenoviruses. These viruses both contain types that are culturable, and hence their viability can be readily determined. Human enteroviruses and human adenoviruses are almost always present in untreated biosolids generated from municipal wastewater, and at concentrations between 10^1 and 10^4 per gram (Sidhu and Toze, 2009; J Hewitt, PhD thesis submitted 2014). If not present, at low concentrations in the untreated product, or at levels below the limit of detection this may be problematic if process efficiency requires evaluating as it may not be possible to determine removal efficiencies.

Methodology

Detection by culture

For culture, a number of different approaches may be used – based on culture, integrated culture and PCR and PCR alone:

- Culturable human enterovirus types readily show cytopathic effect (CPE) and can be quantified using a monolayer or agar cell suspension plaque assay using BGM cells or similar.

- Culturable human adenoviruses, particularly types 40 and 41 that are the most common human adenovirus types in wastewater, do not always readily demonstrate CPE and so plaque assays are not necessarily suitable. Methods such as integrated culture-PCR (C-PCR) that do not rely on the appearance of CPE to detect viral replication can be used to detect viable viruses. This approach has been successful in detecting human adenoviruses that are otherwise difficult to culture. This method is generally a presence/absence assay but could be easily adapted to a quantitative assay by using multiple assays/dilutions and applying a MPN approach to estimate virus concentrations. However, it is recognised that this is more costly and requires further validation before being used routinely.

The current *Guidelines for the Safe Application of Biosolids to Land in New Zealand* (2003), specify that C-PCR is used to enumerate human adenoviruses - this is the same approach as used in a current QMRA project by Sydney Water to monitor pathogen reduction in waste water treatment plants. In that project, human adenoviruses and not human enteroviruses are to be monitored.

The appendix of the current *Guidelines for the Safe Application of Biosolids to Land in New Zealand* (2003) describes methods to recover and to detect human adenoviruses in biosolids and is split into two parts. The first part describes the processing of biosolids to recover enteric viruses. The second part describes the detection of adenoviruses using C-PCR. This method has been extensively evaluated as part of a recently submitted PhD thesis (J Hewitt, PhD thesis submitted) and a number of issues were identified:

1. In the first part, an important concentration step has been (probably inadvertently) omitted. In the second part, the use of BGM cells is recommended for the C-PCR assay. While BGM cells are frequently used for the detection of human enteroviruses, they are not optimal for the detection of human adenoviruses. Instead, HEK-293 cells are better suited for the detection of human adenoviruses, particularly for types 40 and 41. These types are the most prevalent human adenoviruses in sewage and sewage sludge (J Hewitt, PhD thesis submitted; Hewitt et al., 2011). The primers recommended for the detection of adenoviruses detect all adenovirus types, and not just adenovirus types 40 and 41 as indicated in the *Guidelines for the Safe Application of Biosolids to Land in New Zealand* (2003). Work carried out by ESR showed that the integration of real-time quantitative PCR (qPCR) (instead of PCR) in the C-PCR assay was quick, sensitive and integrated well with the workflow.
2. The *Guidelines for the Safe Application of Biosolids to Land in New Zealand* (2003) limit of < 1 PFU enteric viruses /4 g originates from the US EPA methods (US EPA Appendix H: Method for the Recovery and Assay of Enteroviruses from Sewage Sludge). For this to be achieved, at least 4 g of dry weight solids needs to be tested. For the detection of human enteroviruses and adenoviruses, multiple tests are hence required. For an enterovirus plaque assay, this can be readily easily achieved, albeit multiple plates and dilutions are required. For adenoviruses, only 0.25 g biosolids can be tested per assay (depending on the concentration factor), and so as for enteroviruses, multiple replicates are needed so that a total of 1 g can be assayed. This would result in a limit of quantitation of < 1 infectious unit /g. More sample can be tested but this significantly increases the amount of work required and hence cost. The unit 'infectious unit' is more appropriate than PFU – a term solely used for viruses that form 'plaque forming units' - and is more suited to enteroviruses or bacteriophages.

Detection by PCR

Human enteroviruses and human adenoviruses can both also be readily detected using PCR and/or qPCR methods but this does not give any information on viability. Concentrations of viruses by qPCR are usually 2-4 log₁₀ higher than those determined by culture.

Human adenoviruses have been proposed as molecular indices for environmental samples impacted by human wastewater due to their high concentrations, for example in receiving waters (Hewitt et al., 2013). In a New Zealand study, qPCR titres in dewatered anaerobic sludges (n=9) ranged between 10⁵-10⁶ genome copies/g for human adenoviruses and between 10³-10⁵ genome copies/g for human enteroviruses (Hewitt et al., unpublished). A small study on virus presence in New Zealand composted biosolids samples (n=3) showed that final human adenoviruses and enteroviruses were not detected by qPCR and so this approach may be useful for end product verification. This could be a preferred methodology over enteric virus cell culture assays for verification of Grade A composted biosolids, where the objective is to verify that viruses are removed. However, more data on viral composition of composted samples would be required to confirm that such an approach is valid.

Detection of coliphages

Viable bacteriophages (coliphages) can be quantified using a standardised (and US EPA approved) plaque assay (e.g. The APHA 2005 9224 describes 'Methods using coliphages to monitor the microbial quality of water and wastewaters'). Methods include the somatic coliphages assay (9224B), male-specific coliphage assay using *E. coli* Famp (9224C), *Salmonella typhimurium* WG49 (D), single-agar-layer method (9224E), and membrane filter method (9224F).

Coliphages such as male specific F+RNA bacteriophages are present in concentrations between 10² and 10⁴/g untreated biosolids. F-RNA bacteriophages are generally present in lower concentrations in the environment than somatic coliphages. Although coliphages are better indicators of human viruses than faecal bacterial indicators, particularly in relation to the evaluation of process effectiveness, there are uncertainties around their comparative susceptibilities to inactivation processes and in relation to human enteric viruses. The *Western Australian guidelines* (2012) for biosolids management suggest that coliphages are used as enteric virus indicators. However, the suitability of F-RNA and/or somatic bacteriophage as enteric virus indicators is still largely unknown and their suitability as reliable viral indicators is still to be fully assessed. This is supported by the recent review "A review of coliphages as indicators of enteric virus risk in sewage sludges and biosolids" by Robert Humphries and Benjamin Currell (Water Corporation, WA, Australia). The authors sought expert opinion on the rationale for the inclusion of coliphages in the *Western Australian Guidelines for Biosolids Management* (2012). The authors concluded in a summary email to interested parties that

"while coliphages are a useful indicator of enteric virus risk, the Western Australian Biosolids Guideline value is too conservative, and is not scientifically based. To our knowledge no other public health or environmental jurisdiction has adopted coliphages, and there seems to be no evidence that the conventional suite of bacterial indicators has failed. Adoption of excessively conservative indicator values threatens the reuse and recycling of biosolids and other organic wastes that may contain human pathogens."

(Pers comm Dr Robert Humphries Email 29th July 2014).

One rationale for the selection of coliphages over human enteric virus detection by culture methods is that setting up and maintaining a laboratory that has the capability to perform coliphage (F-RNA and/or somatic bacteriophages) assays is simpler than to establish the capability for enteric virus culture. In addition, once established and in routine use, assays for bacteriophages are cheaper than for enteric viruses.

Summary of information

Overall, information on enteric virus infectivity of biosolids is limited with most available biosolids infectivity data relating to enteroviruses, reflecting the established US EPA guidelines. There are few reports on the viability of human adenoviruses, and F-RNA or somatic bacteriophages in biosolids. Furthermore, there is a lack of available data on comparative survival properties through product treatment processes of human enteroviruses, human adenoviruses and coliphages/ bacteriophages. For these reasons, the choice of the indicator is difficult, even without considering the comparative ease of setting up the laboratory and costs involved in testing. As human pathogens, the use of human enteroviruses or human adenoviruses is more informative than the use of bacteriophages. However, the detection of enteric viruses by culture is comparatively expensive as the methods are time consuming and require specialised skills, reagents and equipment, and as such may not be suitable for routine or extensive monitoring.

Recommendation

It is recommended that adenovirus is measured as the virus indicator and that the methodology in the current *Guidelines for the Safe Application of Biosolids to Land in New Zealand* (2003) is modified to reflect the correct adenovirus methodology. It is also recommended that there be an option to analyse samples for human enterovirus as an alternative to human adenovirus. Further investigation of the suitability of using qPCR for end product verification is recommended.

Cryptosporidium/Giardia

In the current *Guidelines for the Safe Application of Biosolids to Land in New Zealand* (2003) it was identified that *Cryptosporidium/Giardia* are “a known problem in New Zealand”. Indeed Cryptosporidiosis and Giardiasis rank 4th and 3rd respectively in a ranking of New Zealand notifiable diseases in 2013 (summarised from appendices to the 2013 ESR Public Health Surveillance report:

https://surv.esr.cri.nz/PDF_surveillance/AnnualRpt/AnnualSurv/2013/2013AnnualSurvTables.pdf)

However, at the time of writing of the *Guidelines for the Safe Application of Biosolids to Land in New Zealand* (2003) it was decided that:

“Current test methods are not yet sufficiently reliable to warrant setting standards for biosolids”.

However, discussions with MPI personnel Gillian Anderson and Andrew Pearson on 2nd of July 2014, raised concerns about *Cryptosporidium* and the prevalence of this organism in cows.

Recommendation

Current test methods for *Cryptosporidium* are still not sufficiently reliable to warrant setting standards for biosolids or other organic wastes.

Helminth ova

The limit of < 1/4g helminth ova in the current *Guidelines for the Safe Application of Biosolids to Land in New Zealand (2003)* was derived from the US EPA Part 503 rule (1993) and was determined to be the detection limit at the time (i.e. 1993). The US EPA Part 503 Rule also requires a viability test. The most up to date biosolids guidelines are those from Western Australian and they require that Strongyloides and Hookworm are monitored with a viable ova limit of <1 per 50 grams of dry final biosolids, but only in certain regions of Western Australia.

Discussions with Sunita Raju, Team leader for microbiology at Eurofins in Wellington, have confirmed the detection limit of < 1/4g for the helminth test (pers comm 21st July 2014). Discussions and email correspondence with Marina Fisher, Senior Laboratory Analyst Microbiology at Watercare on the 22 July 2014 also confirmed the detection limit, and further that they do not undertake the viability testing unless specifically asked as it takes up to 4 weeks. Additionally, the methodology used does not generally identify species of helminth, just 'ova'. Marina also commented that "*we enumerate nematodes and cestodes. We don't see a lot in biosolids samples*". The potential low incidence of helminths in organic wastes may be problematic if verification monitoring has to be continued until they are detected to prove the treatment process can effectively remove them – under these circumstances an option may be to add helminth to pre-treated waste.

In the ANZBP:Review of Biosolids Guidelines (2009)" it was suggested that:

"...the helminth criteria be removed".

Justification for the removal of helminth criteria (email from Paul Darvodelsky), 21 July 2014 was:

"*The recommendation to remove helminth criteria is two-fold. Firstly the risk for most communities is very low because helminths are rarely present. This is not the case however for many indigenous communities in northern Australia. Secondly there are no recognised testing protocols for helminths and testing that has been done to date by seeding sludge with helminths and testing kill rates has been successful, but not what you would call very scientific. Another factor that I would see is that life cycle of helminths is probably pretty well known and if you have a process which meets certain time-temperature criteria then I would expect you could reasonably predict helminth inactivation – is that so?*"

Although there may well be justification to remove helminths as microbial indicators from biosolids monitoring, this might not be the case for other organic wastes that could be included in a new *Organic Wastes Guideline*. Meat works waste and animal manures for example, may well contain higher levels of helminths which could be a potential risk to livestock.

Discussions with the NZ Ministry of Health, Paul Prendergast and John Harding on the 10 June 2014, indicated the inclusion of monitoring for helminth ova removal was originally put forward by MPI (or MAF as they were at the time). Discussion with MPI personnel Emil Murphy once again indicated support for inclusion of helminths in any guideline.

Recommendation

It is recommended that the Steering Group members take direction from MPI on inclusion/exclusion of the helminth in any new guideline. It is also suggested that a survey is undertaken to determine how prevalent helminth ova are in biosolids in New Zealand.

3. Management Controls

Grade B

Grade B biosolids products have no set recommended maximum pathogen levels in the *Guidelines for the Safe Application of Biosolids to Land in New Zealand (2003)*. However, they must undergo processing such as anaerobic digestion to reduce vector attraction and reduce pathogens to levels that they do not pose a threat to public health and the environment as long as actions are taken to prevent exposure to the biosolids after their use or disposal.

Due to the higher levels of pathogens potentially present in a Grade B biosolids, adequate time must be allowed for the biosolids to remain in, or on, the land for natural attenuation to further reduce the pathogens before use of the land for cropping or public access. BUT natural attenuation relies on environmental factors such as temperature, UV, and indigenous microbial competition; these will vary from site-to-site and can't be controlled or predicted. This means that there must be management practices in place that, where possible, provide the "best" abiotic conditions for natural die-off.

Over the last 5 years several New Zealand specific studies have investigated microbial fate and survival in land applied biosolids. Below is a summary of key findings and recommendations.

A study investigating the survival of *E. coli* and *Salmonella* spp. in biosolids applied to a *Pinus radiata* forest (Horswell et al., 2007) found longer survival times of pathogens in cool wet conditions. Thus, they concluded that biosolids' microbes do not like warm dry conditions; apply biosolids when it is warm and dry NOT when it is wet and cold.

The above study also found that withholding periods of greater than 6 months are sufficient to reduce microbial contaminants to background levels. However, a PhD study undertaken by Jason Levitan, (2010) "Die-off of pathogens and assessment of risks following biosolids application in pine plantations" (Murdoch University) found that pathogen re-growth can occur if the conditions are right up to 1.5 years after biosolids were applied to forestry.

A study investigating the mobility and survival of *Salmonella Typhimurium* and human adenovirus from spiked sewage sludge applied to soil columns (Horswell et al., 2010) found that if transported below the top layers of the soil, pathogens can survive for extended periods of time; and that biosolids may enhance mobility and survival, possibly due to enhanced microsite habitat and the addition of nitrogen, thus groundwater contamination from vertical movement of pathogens is a potential risk.

The ANZBP recently produced an update of new literature assessing the risks/hazards and pathogens of primary concern for both Australia and New Zealand (ANZBP 'Pathogen Presence & Pathways Report' Ang, R. 2013), including information on survival and fate of pathogens in soil and vegetation.

"Table 2: Survival and fate of pathogens from wastewater/biosolids in soil and vegetation" below, illustrates that pathogens can survive for extended periods of time in soils.

Table 2: Survival and fate of pathogens from wastewater/biosolids in soil and vegetation.

Organism	Survival in soil	Survival in vegetation	Notes
Bacteria	Days - months. Can survive as long as a year in soil.	Days - months. Can survive as long as 6 months on plants.	Depends on temperature and moisture. Can multiply under appropriate conditions in biosolids, soil, or on vegetation. Much variation in survival time between species. <i>E. coli</i> or thermotolerant coliforms have similar survival dynamics as <i>Salmonella</i> , <i>Campylobacter</i> , and <i>Shigella</i> spp., and can therefore be used as reliable indicator organisms for these pathogens. However, <i>Legionella</i> spp., <i>Leptospira</i> spp., <i>P. aeruginosa</i> , <i>V. cholera</i> , and <i>Yersinia</i> spp. can persist far longer than <i>E. coli</i> .
Helminths	Weeks - years. Can survive as long as 7 years in soil.	Days - months. Can survive as long as 5 months on plants.	Obligatory parasites, therefore unable to multiply in biosolids, soil, or on vegetation.
Viruses	Days – months. Can survive as long as 6 months in soil.	Days - months; generally for shorter periods than in soil, and depends on precipitation, type of vegetation etc. For example, smooth-surfaced tomatoes provided a more favourable environment than on cabbages.	Obligatory parasites, therefore unable to multiply in biosolids, soil, or on vegetation. Temperature is the main controlling factor, with colder conditions favouring survival.
Protozoa	Up to 10 weeks in normal soil; >12 weeks in sterile, autoclaved soil.	Up to 5 days.	Obligatory parasites, therefore unable to multiply in biosolids, soil, or on vegetation. Depends on temperature and desiccation, and variations exist between species.
Fungi and yeasts	At least a year.	Little information.	Affected by pH; they grow better in slightly acid conditions ~pH 5-7.

(Source: ANZBP 'Pathogen Presence & Pathways Report' Ang, R. 2013).

Before lifting site restrictions it is sensible to carry out soil testing to ensure that there has been no cumulative increase in microorganisms due to biosolids application. *Escherichia*

coli is recommended for soil monitoring as it is neither arduous nor expensive, and may provide useful information on pathogen die-off in receiving soils. Control samples (i.e. from an adjacent site that has not had any biosolids applied to it) should be taken before application and at the end of the restraint period to determine 'background' *E. coli* numbers as these may fluctuate naturally (with season), high background levels could also indicate input from feral animals, or from birds. If numbers of *E. coli* are found to be 100 fold higher than background counts, decisions about further restricted access or land-use should be made on a case-by-case basis after consultation with the local Medical Officer of Health (Health Act, 1956). For example, if access is required to fell trees, forest workers could be exposed to elevated levels of pathogens in dust particles. The above approach is also supported in the Western Australian Guidelines (2012) in some circumstances:

“Depending upon the location of the application site, regulatory agencies may request monitoring at the site by the supplier for a specified period. Monitoring after application is to ensure that there are no adverse effects on public health or the local environment.”

Most guidelines state that application of biosolids during heavy rainfall should be avoided.

The Western Australian guidelines for biosolids management (2012) state that:

“The application of biosolids should not occur during rainfall events or when heavy rains are forecast”.

This is also recommended in the current *Guidelines for the Safe Application of Biosolids to Land in New Zealand (2003)*. This is primarily to avoid nutrient run-off but will also reduce the risks of pathogen run-off and the potential to contaminate surface and ground water. Heavy application rates of wastes to soil can increase soil saturation, which can also increase pathogen mobility and decrease moisture loss, and these can increase survival times.

Soil type is a critical factor in determining the potential for microbial leaching from biosolids applied to land – some soils are more high risk than others. This is acknowledged in the *Guidelines for the Safe Application of Biosolids to Land in New Zealand (2003)*, and in section “5.1.2 Soil type” of the Western Australian guidelines for biosolids management (2012). Landcare Research has produced a large body of research on the potential of bypass flow in New Zealand soils (McLeod et al., 2008).

Recommendations

Before lifting site restrictions, carry out soil testing to ensure that there has been no cumulative increase in microorganisms due to biosolids application.

Where possible organic wastes that may contain pathogens should be land applied when the weather is warm and dry.

As activity constraints and withholding periods do not protect against surface-runoff and leaching – it is essential to ensure adequate buffers are in place between the application site and receiving environments (e.g. surface water and groundwater) including food crops in adjoining fields.

Be precautionary when applying large amounts of biosolids to a site (e.g. forest sites where large amount can be applied bi-annually).

Avoid soils with high by-pass flow potential - leaching can be greater on these soils. Even in winter when soil cracks are closed the cracks provide preferential pathways for the movement of water and entrained microbes.

Soil incorporation

Both the *Guidelines for the Safe Application of Biosolids to Land in New Zealand* (2003), and the *Western Australian guidelines for biosolids management* (2012) recommend soil incorporation for biosolids. Soil incorporation is an important risk management strategy as it can:

- Reduce exposure to pathogens
- Remove vector access to pathogens
- Reduce risk of surface run-off
- Increase die-off
- Reduce chances of public contact

The *Western Australian guidelines for biosolids management* (2012) state that:

“...biosolids applied to land in a rural setting should be spread evenly and then incorporated into the topsoil within 36 hours. Incorporation reduces odour problems, vector attraction, nitrogen loss through volatilisation and surface losses due to erosion, and improves the availability of phosphorus.”

Recognising that under some circumstances:

“Soil incorporation may not be compatible with all farming systems (for example, no till agriculture) and certain soil and weather conditions can cause significant environmental harm (for example, soil compaction, dust and erosion). Agricultural application of biosolids without the requirement for incorporation within 36 hours will only be considered for times of year where soil conditions are not suitable for incorporation at the time of conducting the biosolids application.”

The review of the ANZBP: Review of Biosolids Guidelines (2009), determined that soil incorporation was flexible in some states. For example New South Wales, Queensland and Western Australia have a 36 hour incorporation rule; in Tasmania there should be incorporation where possible but not required in all circumstances.

The *Guidelines for the Safe Application of Biosolids to Land in New Zealand* (2003), clearly state that:

“For pastoral land, soil incorporation is a vital risk management tool. As noted in sections 2.2.3 and 2.4, there is concern about the potential to contaminate meat or dairy produce via direct ingestion of pasture and/or surface soil. Consequently, consent conditions relating to discharges of biosolids to pastoral land should also include a requirement for soil incorporation (biosolids can be applied to pastoral land when pasture is resown).”

The *Guidelines for the Safe Application of Biosolids to Land in New Zealand* (2003), go on to state that:

“...consent authorities should attach a condition requiring soil incorporation (pre-planting) on all consents relating to discharges of biosolids to horticultural or cropping land. This will negate the undesirable practice of applying biosolids to leaf, salad, or root crops where there is a risk of direct transfer to animals or humans.”

A need for this requirement will depend on the vector attractant reduction criteria (for example in WA flies are particular vectors of concern), land use (e.g. horticultural land, stock grazing), climate (high rainfall areas will have increased risk of surface run-off if the waste is not incorporated), solids content of the waste (for some wastes a very low solids content may increase risks for leaching/by pass flow if ploughed in). In addition, the implications of this risk management control for the application of other organic wastes such as meat works sludge etc must be assessed as in general resource consents for this type of organic waste do not require soil incorporation.

4. Sampling and monitoring

Verification sampling

The minimum number of samples that should be taken in each monitoring phase and for each grade are detailed in “Table 8.1. Stabilisation grade sampling frequencies” of the *Guidelines for the Safe Application of Biosolids to Land in New Zealand (2003)*,

Table 8.1: Stabilisation grade sampling frequencies

Grade	Monitoring type	Sampling regime	Parameters to be monitored
A	Product verification ^{1,2}	≥ 15 evenly dispersed grab samples per month for a 3-month period with ≤ 3 failures. If > 3 failures then the 15 following consecutive grab samples must comply.	<ul style="list-style-type: none"> ■ <i>E. coli</i> ■ <i>Salmonella</i> ■ <i>Campylobacter</i> ■ enteric viruses ■ helminth ova ■ VAR
	Routine sampling	≥ 1 grab sample per week	<ul style="list-style-type: none"> ■ <i>E. coli</i> ■ VAR
B	Product verification ²	Not applicable for pathogen testing	<ul style="list-style-type: none"> ■ VAR³
	Routine sampling	Not applicable for pathogen testing	<ul style="list-style-type: none"> ■ VAR³

(Source: *Guidelines for the Safe Application of Biosolids to Land in New Zealand (2003)*)

The 15 grab samples mentioned in the above table are not designed to result in statistically representative data.

The *Western Australian guidelines for biosolids management (2012)*, specify collecting only seven samples for pathogen and volatile solids reduction monitoring, the default routine sampling regime is one sample per 300 dry tonnes. For pathogen re-growth, the default sampling regime is three samples tested annually.

In an email (30th July, 2014) offering more explanation, Nancy Penny, Biosolids and Sludge Management Section Leader at The Water Corporation in WA, stated that:

“The WA biosolids guidelines don’t actually have a number of samples to be taken as such for verification of a process. This is typically agreed with the DoH and is dependent on if the process is a new technology (for WA) or if we have existing parameters / concentration to work to. We do have a minimum number of samples to be taken once a process is established and for continuous processes this is based on 1 sample per 300 dry tonne which equates to 1 sample per week. This is also the case for pathogens (E.

coli) which we report as a log reduction for processes that have digesters. To allow for variation we do a rolling geometric mean of 7 samples. Although we do weekly sampling we are only required to report exception through the year with all data reported end of year.”

The US EPA Part 503 Rule (1993) does not specify a number of samples but states in “Table 6-1 Summary of Biosolids Sampling Considerations”

<p>How Should Sampling Be Done and How Many Samples Should Be Taken?</p>	<p>Take either: Grab samples^b (individual samples) for pathogens and percent volatile solids determinations, or Composite samples^b (several grab samples combined) for metals. No fixed number of individual samples required (except for Class B pathogens, Alternative 1, take 7 samples). Enough material must be taken for the sample to be representative. Take a greater number of samples if there is a large amount of biosolids or if characteristics of biosolids vary a lot. See Table 6-4 for guidance (e.g., continuous, instantaneous, or monthly averages required).</p>
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(Source: US EPA; US Environmental Protection Agency (1993) Part 503-Standards for the Use or Disposal of Sewage Sludge. Federal Register 58, 9387-9404.)

Routine sampling

The current *Guidelines for the Safe Application of Biosolids to Land in New Zealand* (2003), require > 1 grab sample per week for *E. coli*.

In an email communication from Paul Darvodelsky on 25 July 2014, he related a conversation with Al Rubin from the USA:

“In general they require a minimum of about 1 sample per year. The logic however was that there are three parts of the guidelines which protect human health and the environment. These are contaminant/pathogen levels, management practices and sampling and monitoring (knowing what’s happening). The US EPA’s view was that the levels set when combined with the management practices gave such a conservative approach that there was little need to also add the burden of a high level of sampling and monitoring. It was deemed unlikely that many utilities would not follow the guidelines and therefore the risk to community was therefore very low. Because of the cost of sampling and monitoring they relaxed this section of regulation.”

However the requirement in the current *Guidelines for the Safe Application of Biosolids to Land in New Zealand* (2003) of > 1 grab sample per week for *E. coli* is not expensive or arduous bearing in mind that sampling for other chemical parameters is likely also being undertaken at the same time.

Recommendation

It is recommended that number of samples required for verification sampling be reduced from 15 to 7, in line with the Western Australian guidelines for biosolids management (2012).

PRIMARY SECTOR RELATED ORGANIC WASTE

Wastes included in this category are agricultural wastes such as meat works waste, manure (e.g. chicken, pig) and animal bedding (poultry industry wood shavings and bark).

Pathogens of primary concern in animal wastes

The major source of pathogens in animal manure that are of risk to humans are similar to those found in human sludge and are summarised in the table below.

Table 3. Select pathogens found in animal manure.

Pathogen	Disease
<i>Bacillus anthracis</i>	Anthrax
Vero cytotoxin-producing <i>Escherichia coli</i> O157 (VTEC O157)	VTEC O157 is found in the faeces of healthy livestock and is not necessarily associated with disease or production loss. The organism is excreted in both faeces and saliva and is a potential risk to people working in close contact with, or visiting, farm animals and their environment. Excretion is intermittent and variable and the organism can survive for long periods of time in the environment (several months), which is thought to be important in maintaining infection within the herd through re-infection.
<i>Leptospira pomona</i>	Leptospirosis
<i>Listeria monocytogenes</i>	Listeriosis
<i>Campylobacter</i> species	<i>C. jejuni</i> and <i>C. coli</i> rarely, if at all, cause disease in animals under natural conditions. Nevertheless, surveys indicate that the intestinal carriage rate is high in healthy farm animals, poultry, pets, and wild birds and environmental contamination with <i>Campylobacter</i> species from faecal material is frequent.
<i>Salmonella</i> species	When livestock, particularly poultry and pigs, become infected with <i>Salmonella</i> , they frequently become carriers of the infection without showing any clinical signs of ill health. Infection, however, may occasionally result in disease such as enteritis, abortion, septicaemia, or death. Some serotypes or strains may cause particularly severe illness, especially in ruminants. Livestock are normally kept in groups, so one infected animal may pass the organisms to others within the group. In many cases, carriage of <i>Salmonella</i> in groups of farm animals resolves spontaneously but cycling of infection between different groups of animals may prolong the persistence of infection on some farms.
<i>Clostridium tetani</i>	Tetanus

<i>Histoplasma capsulatum</i>	Histoplasmosis
<i>Microsporium and Trichophyton</i>	Ringworm
<i>Giardia lamblia</i>	Giardiasis
<i>Cryptosporidium</i> species	Infection may be found in clinically normal livestock. When disease occurs, it is most often seen in young animals, particularly calves, but also lambs and occasionally piglets. In lambs an infection with <i>Cryptosporidium</i> is often asymptomatic despite excreting in excess of 5×10^6 oocysts per gram of faeces. These non-clinical, highly infectious cases pose a risk to both the public, and the veterinary health of other livestock as there are no indications to isolate these animals from other livestock or human contact. Co-infection with other pathogens such as rotavirus and <i>E. coli</i> may also be present during clinical disease outbreaks. Clinical signs include diarrhoea, weight loss and anorexia.

(Source: WHO. 2012. Animal Waste, Water Quality and Human Health. A Dufour, J Bartram, R Bos, et al (eds). Published on behalf of the World Health Organization by IWA Publishing, UK. 489 pp. http://www.who.int/water_sanitation_health/publications/2012/animal_waste/en/; Ministry of Health. 2013. Guidelines for Drinking-water Quality Management for New Zealand 2013. Third edition. Wellington: Ministry of Health.)

Dairy Shed Effluent (DSE)

Discharge of DSE is a permitted activity and is well controlled by both Regional/District Councils and Dairy NZ. There are a number of good management practice guidelines available from the Dairy NZ website.

Recommendation

Dairy Shed Effluent should not be considered under this guideline.

Animal wastes that are treated to meet Grade A

The microbial indicators required for verification testing under the current *Guidelines for the Safe Application of Biosolids to Land in New Zealand (2003)* also represent the major group of risk organisms potentially found in animal manures and meat works wastes.

Recommendation

If a product is to be sold and/or handled by the public then it should effectively be pathogen free and be subject to the same treatment as a Grade A biosolids.

Animal wastes that are treated to meet Grade B

The land application of wastes such as piggery manure is a controlled activity under the Resource Management Act and requires resource consent.

In general there are currently no requirements to process agricultural wastes to reduce pathogens prior to land application. For these wastes the main risk mitigation is “good husbandry practices” and ensuring that wastes from pigs, poultry and dairy cows should be free of major diseases. Management controls such as:

- Proximity to groundwater: do not apply effluent to land within 50m of any wells or bore used for water supply purposes.
- Proximity to surface water: do not apply effluent to land within 25m of a surface water body.
- Suitable withholding periods prior to grazing (allowing maximum exposure to sunlight)
- Application well away from public places, cropping paddocks and horticultural blocks as disease causing micro-organisms may live in the effluent and can pose a risk to both animal and human health
- (Sources: Appendix VIIC Taranaki Regional Freshwater Plan; Dairy NZ Effluent Resources, DNZ40-001.)

The Biosecurity (Ruminant Protein) Regulations (1999) place certain restrictions on the disposal of wastewater from the meat processor and rendering plants on land where ruminant animals may graze. The following advice is given for the surface application of materials to pasture and also applies to farmland generally:

- Paunch contents and manure may be applied to pasture.
- Ruminant animals may graze on land where such paunch contents and/or manure have been applied provided there are no visible signs of gut material/ ruminant protein. Ideally the paunch material will have been composted first.
- Before applying to pasture, slaughterhouse and rendering plant wastewater must be treated to remove float materials and sediments, and screened to the extent that it is suitable for spray irrigation. Ruminants may graze on pasture where wastewater has been applied provided the land and the vegetation are not visibly contaminated by the wastewater.
- Pasture may be harvested for feeding to ruminants provided the land and the vegetation are not visibly contaminated by the wastewater.
- Slaughterhouse and rendering wastewater treatment plant sludge may be applied to pasture provided the floating debris and settled solids in the wastewater were removed prior to treatment. Ruminant animals may graze on land where such sludge has been applied.

Poultry litter management

Bedding material for meat chickens, turkeys, ducks and layer hens consists of wood shavings and bark. The poultry industry generally removes litter from their operations regularly though-out the year and the used litter (thousands of tonnes) is generally spread on fields such as general land/farming applications, spread on dairy pasture and spread on mushroom/maize fields; a very small amount is composted.

(Source: Poultry management in New Zealand: production, manure management and emission estimations for the commercial chicken, turkey, duck and layer industries within New Zealand MAF Technical Paper No: 2012/15 Report prepared for Ministry of Agriculture and Forestry By Poultry Association of New Zealand and Egg Producers Federation of New Zealand April 2012).

Recommendation

There appear to be limited safeguards to protect public and animal health from potential pathogens in land applied animal wastes. It is recommended that as for biosolids these wastes must undergo some form of process to reduce pathogens so that they do not pose a threat to public health, animal health or the environment; if these process controls are combined with management practices (as set out under the *Guidelines for the safe application of Biosolids to land in New Zealand* (2003) with respect to buffer distances, with-holding periods etc) the risk of microbiological hazards impacting livestock or human health is low.

RECOMMENDATIONS AND CONCLUSIONS

Many organic wastes have commonality in terms of the pathogens that they contain and in eventual end-use (e.g. soil compost or conditioner). This review provides recommendations for microbial quality criteria for beneficial re-use of organic wastes based on protection of public health.

The *Guidelines for the Safe Application of Biosolids to Land in New Zealand* (2003) are the most comprehensive guideline with respect to microbial quality criteria for organic wastes. Strongly based on the US 40CFR503 rule (1993), they provide detailed descriptive guidance to potential biosolids users and describe “good practice”. Since the development and release of the US regulations there has been a significant development of understanding of biosolids use, and the scientific understanding of the impacts and benefits of biosolids (and organic wastes as a whole) has progressed. In addition, there have also been a number of studies undertaken that can provide more information specific to New Zealand’s soils, climate and production systems. This review aims to summarise recent advances in biosolids practice and research and provides recommendations for a new ‘Organic Waste Materials Guideline’.

The opportunities for improving and rationalising organic waste regulation, based on an expansion of the *Guidelines for the Safe Application of Biosolids to Land in New Zealand* (2003) to integrate other wastes are discussed below in the form of a number of questions.

What is the justification for the inclusion of the following pathogens: *E. coli*, *Campylobacter*; *Salmonella*; enteric viruses; helminth ova, in the current *Guidelines for the Safe Application of Biosolids to Land in New Zealand* (2003)?

Any new guideline should retain the two pathogen grades A and B. The highest level of pathogen treatment should produce a product that is effectively ‘pathogen free’ and able to be directly handled by the public with minimal public health risks.

Pathogen reduction requirements for Grade A products should be performance based as opposed to process based. The microbial indicators of a range of pathogens are required to prove pathogen destruction; monitoring *E. coli* alone is not adequate. The microbial indicators in the current *Guidelines for the Safe Application of Biosolids to Land in New Zealand* (2003) are justified and should be retained with respect to: *E. coli*, *Salmonella spp.*, *Campylobacter spp.* and enteric virus. *E. coli* are used internationally as a biological indicator of faecal pollution; *Salmonella spp.* are traditionally used as an indicator for bacterial removal; *Campylobacter spp.* are required in New Zealand due to the high incidence of campylobacter infection. Human adenoviruses and enteroviruses are suitable indicators for removal of virus by treatment processes. Decisions on retention of helminth ova monitoring should be made by The Ministry for Primary Industry based on risks to live stock.

Are there any other pathogens that should and should not be in a new guideline?

For *Cryptosporidium*, there is some justification for inclusion of this organism in microbial monitoring for Grade A products, due to prevalence and impacts on livestock, and high

disease rate in humans. Data from a comprehensive study undertaken by Sydney Water, monitoring the efficiency of sewage treatment processes on removal of a number of microbes, including *Cryptosporidium*, will aid decision making.

Do other organic wastes contain additional pathogens of concern that should be included in a new guideline?

The microbial indicators recommended for monitoring in organic wastes derived from human wastes (discussed above) represent the major group of risk organisms potentially found in animal manures and meat works wastes and will adequately assess any potential risks.

Are the detection methods/limits for pathogens in the current *Guidelines for the Safe Application of Biosolids to Land in New Zealand (2003)* adequate?

Over the last ten years there has been significant method development in the area of environmental microbiology. For the microbial indicators that must be measured for verification monitoring to produce a product that is safe to be handled by the public (i.e. Grade A), limits should be based on methodological detection limits.

The current methods described for the recovery and detection of human adenoviruses in biosolids in the appendix of the *Guidelines for the Safe Application of Biosolids to Land in New Zealand (2003)* has been extensively evaluated as part of a recently submitted PhD thesis (J Hewitt, PhD thesis submitted). An important concentration step has been (probably inadvertently) omitted. There are also modifications required in the detection step, including choice of cell line. Hence the methods need to be amended. An option to analyse samples for human enterovirus as an alternative to human adenovirus would also be useful. Molecular methods such as qPCR, although unable to report on viability, could be relevant for end product verification.

Methods sourced from the Sydney Water, once available, should be reviewed especially for *Cryptosporidium* and helminths.

What additional controls are important for land application of organic wastes that may still contain pathogens (e.g. Grade B)?

Management restrictions and guidance in *Guidelines for the Safe Application of Biosolids to Land in New Zealand (2003)* should be retained in a new 'Organic Waste Materials Guideline' with respect to managing public health risks from the land application of organic wastes that have lower levels of treatment (e.g. Grade B). Adequate time must be allowed for the product to remain in, or on, the land for natural attenuation to further reduce the pathogens before use of the land for cropping, stock grazing or public access. Restrictions such as buffer zones must be in place to prevent contamination of ground and surface waters.

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24th July 2017

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Dear Nick

Submissions on first draft of Organic Materials Guideline

The draft “Beneficial use of organic waste products on land” guideline was published for external review by stakeholders in December 2016. Five regional meetings were held to discuss the draft during February 2017, over 100 people attended. Twenty-three submissions from 36 individuals and organisations were subsequently received. The project Steering Group held a meeting to consider these submissions on 27 April 2017. Several of the responses raised issues regarding the management of microbial contaminants and I have been asked to respond.

The submissions are summarised in Table 1 below.

Table 1. Summary of submissions relating to management of microbial contaminants

Submitter	Detail
Water Care	Section 6.8 indicates that soil should be tested for <i>E. coli</i> . It is not clear why this is recommended. The site restrictions and exclusion periods have been shown to be adequately protective for pathogen management. This type of testing of the soil would not provide useful information for managing risks of pathogen exposure.
	Stock exclusions We recommend that the time period between biosolids application and stock access or harvest be reviewed. A 6-month exclusion period differs from regulations used in other countries (generally a 30-day exclusion period). A 6-month exclusion time is unnecessarily prohibitive and would not fit into current farming practices where a type B biosolids could otherwise be utilised.
Hutt valley DHB	We recommend that the wording in Section 6.8, page 23, around when soil should be tested pre application of organic waste materials is clarified as it is difficult to determine this from the text, for example, it appears to read that soil testing (for existing contamination and background <i>E. coli</i>) is only recommended prior to application of Type 1B and 2B materials. A table of recommended soil sampling pre and post application will provide clarity for each type of organic waste material. It will be important to emphasise that although the level of contaminant (chemical or pathogen) accumulation will be captured by post application monitoring, decisions about the appropriateness of the site being utilised for application are necessary prior to commencement. This type of risk assessment can take into consideration the current planned use of the site and consider potential impacts of future use in relation to likely levels of accumulated contaminants.

	These aspects could be added to the Land Application Site Management Plan and Nutrient Management Plan (Sections 7.2 and 7.3, page 30)
	Section 9.6, page 39, recommends background soil testing for <i>E. coli</i> concentrations. It would be useful to clarify if this guidance is intended for all types of organic waste material or only certain types. The section states 'If numbers of <i>E. coli</i> are found to be 100 fold higher than background counts, decisions about further restricted access or land-use should be made on a case-by-case basis after consultation with the local Medical Officer of Health (Health Act, 1956).' Regional Public Health would like to understand the evidence base of this recommended trigger level for notification to the Medical Officer of Health. Although useful to have a numerical trigger level, the risk will also depend on the proposed activities for the site and likely exposure risk

The following resources have been used to consider the points raised by the submitters in table 1 above:

- US EPA; US Environmental Protection Agency (1993) Part 503-Standards for the Use or Disposal of Sewage Sludge. Federal Register 58, 9387-9404.
- Western Australian guidelines for biosolids management (2012) Department of Environment and Conservation
- New South Wales Environmental Protection Agency (2000) Use and Disposal of Biosolids Products.
- Email conversations with Paul Darvodelsky (PSD Australia)

Below I have outlined the response to the submissions.

Stock withholding periods and site restrictions

The goal of site restrictions is to limit site activities such as harvesting and grazing until pathogens potentially present in biosolids have been reduced by environmental conditions such as temperature and UV.

The current Guidelines for the Safe Application of Biosolids to Land in New Zealand (2003) suggest a stock withholding period of 6 months after Grade B biosolids have been applied to "fodder crops, and pasture, orchards where dropped fruit is not harvested, turf farming, industrial or nonedible crops, crops that will be peeled or cooked before eating". This is a precautionary approach and was also suggested in the draft "Beneficial use of organic waste products on land" guideline (December 2016). One submitter has requested this time period be reviewed and reduced to 30 days.

There are very few New Zealand specific studies investigating microbial fate and survival in land applied biosolids. A study investigating the survival of *E. coli* and *Salmonella* spp. in biosolids applied to a *Pinus radiata* forest (Horswell et al., 2007) found that *E. coli* numbers did not reduce to background until 13 weeks after biosolids application during the Autumn/Winter in optimal conditions, but in the summer rapidly reduced by week 3. A PhD study undertaken by Jason Levitan, (2010) "Die-off of pathogens and assessment of risks following biosolids application in pine plantations" (Murdoch University) found that pathogen re-growth can occur if the conditions are right up to 1.5 years after biosolids were applied to forestry.

The Western Australian (WA), New South Wales (NSW) and The US EPA Part 503 rule guidelines for biosolids management require only a 30 day withholding period for animals grazing. For lactating and new borns this is extended to 45 days in WA and 90 days in NSW. As an example, the WA withholding periods are shown below.

Table 14: Withholding periods (Western Australian guidelines for biosolids management (2012))

Table 14: Withholding periods

Activity	Withholding period for pathogen grade P2 and P3
Food crops that may be consumed raw but not in contact with biosolids	No fallen fruit is to be collected for human use.
All other food crops	Must not be harvested for 30 days after biosolids incorporation.
Animal feed and fibre crops	Must not be harvested for 30 days after biosolids application/incorporation.
Animal withholding periods	Animals must not be grazed on the site for 30 days after biosolids application/incorporation. ²³ Lactating (including milk for human consumption) and newborn animals should not be allowed to graze the site for 45 days after biosolids application. Poultry and pigs must not be grazed for at least one year on land subject to previous biosolids application; their feeding habits result in high levels of ingested soil.
Turf	Turf grown on land to which biosolids have been directly applied must not be harvested for at least one year after biosolids application/incorporation.
Forestry and timber plantations	Public access to forestry and timber plantation biosolids application areas should be restricted for 12 months.

²³ Source – NSW EPA Environmental Guidelines, 1997

For WA, NSW and US EPA, restrictions for turf are one year as opposed to 6 months in the NZ guideline. The accompanying literature to the WA, NSW and US EPA guidelines indicate this is due to the possibility that turf may be placed on a lawn or on land with high potential for public exposure. The US EPA Part 503 rule reduces this to 30 days if the turf will have restricted public access.

One major difference between the aforementioned guidelines and those in NZ (current and proposed) is that the NZ guidelines only specify vector reduction processes for Class B biosolids (Table 6.2 of current guidelines and Table 9.1 draft guidelines).

The processing of biosolids in the WA guidelines, P2 and P2, require “1.5 log reduction (pathogen count reduced by 1.5 orders of magnitude from start to finish of sludge treatment process) and >38% Volatile Solids Reduction”. The NSW EPA (2000) guidelines, for restricted use biosolids (equivalent to NZ Class B) must meet at least one pathogen reduction requirement and at least one vector attraction reduction requirement (Table 3-3 in NSW guideline). The US EPA (1993) guidelines specify “Processes to Significantly Reduce Pathogens (PSRPs)” reduce faecal coliform densities to less than 2 million CFU or MPN per gram of total solids (dry weight basis) and reduce Salmonella sp. and enteric virus densities in sewage sludge by approximately a factor of 10. Under Part 503.32(b)(3), sewage sludge meeting the requirements of these processes is considered to be Class B with respect to pathogens PSRPs. As an example the sludge processing suggested/required in the WA guidelines for biosolids management P2 and P3 are show in the exerts of Table 2 below. These treatment methods are more stringent than those specified in the Guidelines for the Safe Application of Biosolids to Land in New Zealand (2003) (Exert from Table 6.2).

Exert from Table 2: Approved treatment methods (Western Australian guidelines for biosolids management (2012))

Pathogen grade	Approved treatment methods *1	Maximum pathogen levels ²	Other conditions
	Other accepted processes		Process verification requirements
Grade P2 Low pathogen levels with some regrowth potential	Composted at >53°C for 5 days or >55°C for 3 days	<i>E. coli</i> ² – less than 1,000 counts per gram of dry final biosolids Strongyloides & Hookworm (viable Ova) <1 per 50 grams of dry final biosolids (only required north of the 25 th parallel)	Final biosolids do not generate offensive odours when coupled with management controls Weed seed controls may be needed in agricultural or landscape applications Compost may need to be matured to ensure toxic organic compounds do not subsequently affect plant growth
	Heated to 70°C for 1 hour and then dried to >90% solids		Final biosolids do not generate offensive odours when coupled with management controls Final product to be kept dry until applied
	Digested, heated to 70°C for 1 hour and then dried to >75% solids		Final biosolids do not generate offensive odours when coupled with management controls, and with a volatile solids reduction of >38%
	Aerobic thermophilic digestion (55-60°C for 10 continuous days), and a total solids reduction of >50%		Process verification requirements
Other accepted processes, e.g. storage where safety can be demonstrated			
Grade P3 Low- Medium pathogen levels with some regrowth potential	Anaerobic digestion ≥15°C for ≥60 days	<i>E. coli</i> ² – less than 2,000,000 counts per gram of dry final biosolids Strongyloides & Hookworm (viable Ova) <1 per 50 grams of dry final biosolids (only required north of the 25 th parallel)	Final biosolids do not generate offensive odours when coupled with management controls, and with a volatile solids reduction of >38%
	Aerobic digestion at ≥20°C for ≥40 days or at ≥15°C for ≥60 days		Lime amended biosolid (LAB) product is applied within 7 days
	Addition of lime so that pH is maintained at >12 for >3 hours		Final biosolids do not generate offensive odours when coupled with management controls Weed seed controls may be needed in agricultural or landscape applications
Aerobic composting at >40°C for ≥5 days, including at least 4 hours at >55°C. Process control as per AS 4454–2003			
	Mesophilic anaerobic digestion at 35°C ± 3°C for ≥15 days	Minimum pathogen reduction of 1.5 log reduction through digestion (pathogen count reduced by 1.5 orders of magnitude from start to finish of sludge treatment process)	Trigger value <i>E. coli</i> – less than 2,000,000 counts per gram of dry final biosolids, with a volatile solids reduction of >38%
	Other accepted processes		1.5 log reduction (pathogen count reduced by 1.5 orders of magnitude from start to finish of sludge treatment process) and >38% Volatile Solids Reduction

Exert from Table 6.2: Recommended controls for stabilisation Grade B biosolids, depending on end use (Guidelines for the Safe Application of Biosolids to Land in New Zealand (2003))

Land use	VAR requirement (see Table 4.1)	Recommended controls
<p>Fodder crops and pasture, orchards where dropped fruit is not harvested, turf farming, industrial or nonedible crops, crops that will be peeled or cooked before eating</p>	<ul style="list-style-type: none"> ■ Mass of volatile solids in biosolids shall be reduced by a minimum of 38%; or ■ SOUR @ 20°C < 1.5 g/m³ for liquid sludges from aerobic processes; or ■ pH > 12 @ 25°C for at least 2 hours and pH > 11.5 for 22 more hours. ■ Storage/exclusion period. 	<p>May be applied immediately. Plus Soil incorporation (see section 6.11). Plus Fruit and turf should not be harvested or pastures grazed for at least 6 months after applications. Plus Crops that will be peeled or cooked should not be harvested for at least 6 months after application.</p> <p>Store or lagoon for at least 1 year prior to application Plus Soil incorporation (see section 6.11). Plus Fruit and turf should not be harvested or pastures grazed for at least 6 months after applications. Plus Crops that will be peeled or cooked should not be harvested for at least 6 months after application. May be applied immediately.</p>

Table 9.1 of draft “Beneficial use of organic waste products on land”

Table 9-1 Application methods and exclusion times for type 1B and 2B products

Requirement	Land Use			
	Salad crops, fruit or other crops for human consumption that may be eaten unpeeled or uncooked	Public amenities, sport fields, public parks, golf courses, play grounds, and land reclamation	Fodder crops and pasture ¹ , turf farming, orchards where dropped fruit is not harvested, industrial or non-edible crops, crops that will be peeled or cooked before eating	Forest, trees or bush scrubland
One of those indicated below before application to land:				
Reduction of the mass of volatile solids by ≥ 38 %	✓	✓	✓	✓
SOUR @ 20°C ≤ 1.5 g/hr/m ³ for liquid biosolids from aerobic processes	✓	✓	✓	✓
pH ≥ 12 @ 25°C for ≥ 2 hours and pH ≥ 11.5 for 22 more hours	✓	✓	✓	✓
Store for ≥ one year	✓	✗	✓	✓
Store for ≥ six months	✗	✓	✗	✗
All of those indicated below after application to land:				
Soil incorporation undertaken within 1 day of the product application, except for application to forested land	✓	✓	✓	✗
An exclusion time ≥ 1 year before salad crops, fruit or other crops for human consumption that may be eaten unpeeled or uncooked are sown	✓	✗	✗	✗
Restrict public access until full vegetative cover is established on the discharge site.	✗	✓	✗	✗
No grazing or harvesting of crops, turf or fruit for ≥ 6 months	✗	✗	✓	✗
Restrict public access for six months and fence and sign buffer zones	✗	✗	✗	✓

The current and draft New Zealand guidelines do not specify any log reduction in pathogens for Grade B biosolids. Recommended controls for stabilisation of Grade B biosolids are given in Table 6.2 of the guideline (or 9.1 of the draft) and focus on vector attraction reduction only; pathogen reduction is facilitated by land management controls (e.g. withholding periods).

The limited New Zealand specific literature suggests that the time taken for natural attenuation to occur, and for microbial contaminants to reach background will depend on a number of variables which can't be easily controlled. Hence the precautionary 6 month withholding period. This variability is born out in the WA guidelines where site monitoring is suggested in some circumstances:

“Depending upon the location of the application site, regulatory agencies may request monitoring at the site by the supplier for a specified period. Monitoring after application is to ensure that there are no adverse effects on public health or the local environment.”

It should also be noted that climatic conditions differ between countries and factors that influence microbial die-off, such as hot dry weather, may be more common in some countries

than in others. For example a 30 day withholding period in the summer in Western Australia may facilitate rapid die-off of any pathogens remaining in the biosolids, whereas a cool wet summer in NZ may not.

Due to the paucity of NZ specific data on pathogen die-off in biosolids application sites, it is likely sensible to default to the current 6 month stock exclusion unless evidence can be provided to indicate that pathogens have died off more rapidly. This could be shown by conducting site monitoring for *E. coli*. *Escherichia coli* is recommended for soil monitoring, control samples (i.e. from an adjacent site that has not had any biosolids applied to it) should be taken before application and at the end of the restraint period to determine 'background' *E. coli* numbers as these may fluctuate naturally (with season), high background levels could also indicate input from feral animals, or from birds. If numbers of *E. coli* are found to be 100 fold higher than background counts, decisions about further restricted access or land-use should be held with the consenting authority.

Based on the single NZ study (Horswell et al., 2007), a 3 month stock exclusion followed by testing to ensure that there has been no cumulative increase in microorganisms due to biosolids application could be recommended in the guidelines.

Background soil testing for *E. coli* concentrations

A phone conversation was held with Dr Jill McKenzie, Medical Officer of Health Hutt Valley DHB (HVDHB) regarding their submission (Table 1). The concern regarding background testing for *E. coli* was not related to the testing per-se, more the suggestion to consult with the local Medical Officer of Health. The HVDHB felt this was inappropriate and that this should be dealt with in the Resource Consent in monitoring requirements for the site. This is a reasonable suggestion.

Recommendations:

There is not enough evidence or scientific studies to reduce the stock exclusion to 30 days in line with other international guidelines. Stabilisation processes and climatic conditions are different to those in the current NZ biosolids guidelines and in the proposed guidelines.

There is also not enough evidence to reduce the stock exclusion to less than 6 months unless it can be proven that there are no adverse public health impacts (i.e. no pathogens remaining in the sludge). Possible wording could be:

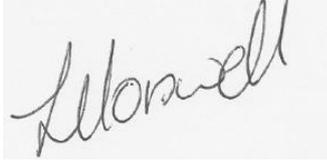
*“Depending upon the location of the application site, and the biosolids treatment method, stock exclusion may be lifted after 3 months if *E. coli* monitoring at the site indicates there are no adverse effects on public health or the local environment.”*

The possible reduction in stock exclusion and site monitoring would need to be incorporated into a resource consent.

The information in this report and the recommendation should be discussed by the Steering Group to come up with a final recommendation.

If you have any questions regarding the matters dealt with in this letter please do not hesitate to contact me.

Kind regards

A handwritten signature in black ink on a light grey background. The signature is written in a cursive style and appears to read 'Jacquie Horswell'.

Jacqui

Dr Jacquie Horswell PhD

Programme Leader: Centre for Integrated Biowaste Research



5 TRACE ELEMENTS REVIEW

This section is available as a separate report: CIBR Publication 011 Contaminants Review August 2014 which updates section 2 metal contaminant information which is available as a separate download [here](#). This document

- ◆ Summarises existing knowledge on trace element contaminants in organic wastes;
- ◆ Reviews justification for the Guidelines nitrogen (N) loading;
- ◆ Reviews the justification for inclusions of limits for specific trace elements;
- ◆ Determines if other trace elements of concern should be included; and
- ◆ Provides recommendations with supporting logic.

DRAFT FOR
PUBLIC COMMENT



Centre for Integrated Biowaste Research

'Organic Materials Guidelines - Contaminant Review'

Jürgen Esperschütz and Brett Robinson

Peer reviewed by Jacqui Horswell (and a further review to be decided)



Centre for Integrated Biowaste Research

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Centre for Integrated Biowaste Research

‘Organic Materials Guidelines - Contaminants Review‘

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August 2014

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Centre for Integrated Biowaste Research

1. EXECUTIVE SUMMARY

- This draft report comprises the major findings of a literature review on guideline limits for the concentrations of the chemical elements in biowastes. This preliminary report is for use by Water NZ and not intended to be used as the final document upon which the guidelines are eventually based.
- The land application of biowastes improves physical, chemical and biological soil conditions, but can also result in excessive nitrate leaching and / or TE accumulation in soil and plants. In this respect, the addition of biowastes to soil is similar to the application of fertiliser.
- Currently, biowaste application to land is mainly limited by its N content, to avoid excessive N leaching. However, while N is regulated on the basis of total N, only mineralised N can be taken up by plants. Therefore, the N application via biosolids is often insufficient for adequate plant growth; hence current guidelines are too restrictive for certain application scenarios.
- For the continual application of biosolids, nitrogen concentrations should not exceed current regulatory guidelines of **200 kg N / ha / year**, whereas biosolids application to rebuild degraded soils should be limited based on a concentration of **150 kg / ha of mineral N**.
- Currently, the trace element concentrations in New Zealand biosolids can be used to categorize the biosolids as grade “A” or “B”. The threshold values for trace element (TE) concentrations in grade “A” biosolids currently prevent the beneficial reuse of these materials. In most situations, using biosolids that do not meet grade “A” TE concentrations would not cause soil TE concentrations to exceed internationally-recognised guideline values. Moreover, the threshold concentrations for TEs in NZ’s grade “A” biosolids are significantly lower than international values.
- In many cases, the addition of Zn and Cu to soil via biosolids could provide agronomic benefits to many NZ soils that are deficient in these essential micronutrients.
- Biosolids and other biowastes could be safely and beneficially reused if their application does not cause soil TE concentrations to exceed internationally-recognised guideline values. Therefore, the current TE concentration thresholds for biosolids to be categorized as grade “A” could be abandoned, while leaving in place current grade “B” thresholds to prevent dumping of overly-toxic materials.
- Current NZ soil guideline values for biosolids disposal are higher than those used internationally. We suggest that soil guideline values for biowastes are consistent with the NZ national standards currently under development. Assuming these are similar to internationally-recognised guideline values, the eventual NZ standards will not be overly restrictive for the beneficial reuse of biowastes. **In contrast, the proposed system will enable the beneficial reuse of more biowastes.**
- Example scenarios have been calculated using European soil TE guideline values. Calculations reveal that most NZ soils could be amended with at least 125 tonnes (total over several years) of biowastes at the current grade “B” threshold without causing soils to exceed these guidelines. If NZ adopts higher soil guideline values, then greater amounts of biosolids could safely be added.
- This approach for the beneficial reuse of biowastes is consistent with the approaches used by fertiliser companies, for example the Tiered Fertiliser Management Strategy for cadmium, which is used by the NZ fertiliser industry.

2. INTRODUCTION AND CONTEXT

2.1. Purpose of the revised report

Organic wastes are derived from animal manures, crop residues, food processing wastes, municipal biosolids and wastes from some industries (Westerman & Bicudo, 2005). Increases in population and wealth have resulted in an increased production of biowastes that require sustainable management strategies for their disposal and recycling (Panagos *et al.*, 2013; Río *et al.*, 2011). The application of organic wastes to land can improve the physical, chemical and biological fertility of soils. However it is well known that these wastes can also carry unwanted TEs that may impact soil health and function when present in high concentrations (Bolan *et al.*, 2014).

The current *Guidelines for the Safe Application of Biosolids to Land in New Zealand (2003)* (NZWWA, 2003), state that risk management considerations, permissible loading rates and public health risks apply depending on its land use. A new *Organic Material Guideline* should consider that biowastes can be used either as a continual soil conditioner, or an amendment that is used in a single application, for example to rebuild a degraded soil. The environmental outcomes of each practice are distinct and consequently different limits and guideline values will be given for each practice. The purpose of this report is to:

- a. Summarise existing knowledge on trace element contaminants in organic wastes relative to the current *Guidelines for the Safe and Application of Biosolids to Land in New Zealand (2003)*
- b. Review justification for the nitrogen (N) loading rate of no more than 200 kg N per hectare per year (averaged over three years)
- c. Review the justification for the inclusion of limits for the following TEs: arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), mercury (Hg), nickel (Ni), and zinc (Zn)
- d. Determine if other organic wastes contain additional TEs of concern that should be included in a new guideline
- e. Review the allowable concentrations of trace elements in biosolids (Table 4.2 in current *Guidelines for the Safe Application of Biosolids to Land in New Zealand (2003)*), and provide recommendations for new limits for waste that will not cause waste-amended soil to approach the soil contaminant limits (using the current soil limits in Table 4.2 noting that these might change under the new Soil Health Indicators Envirolink Project).
- f. Provide recommendation for the above with supporting logic
- g. Determine possible wastes that may be included in a new guideline include but are not limited to:
 - Household organic (Food waste green waste)
 - Paper and cardboard
 - Primary sector related organic waste (e.g. Agricultural wastes (big in volume but small in practice in some cases), Meat works waste, Manure, chicken manure)
 - Sewage sludge
 - Pulp and paper waste
 - Nappies and sanitary
 - Medical Waste

2.2. Existing knowledge on trace element contaminants in organic wastes

Major sources for most Trace Elements (TEs) to enter the soil are fertiliser, manure and organic amendments. Due to their long residence time in soil, and long-term application the accumulation of TEs in soil are potential risks for quality assurance in the human food chain but may also impact soil health and function and plants growth. High concentrations of TEs can result in reduced plant growth (Zn, Cu, Ni), endanger the human food chain via crop uptake (Cd) and direct ingestion (Hg), or negatively influence animal health (Cu, Pb) and soil microbial processes (Zn) (Smith, 2009). However, various parameters have to be taken into account when assessing TE application via organic waste amendments, since TE bioavailability in soil depends on the chemical association within the soil matrix, soil pH, the concentration of the element in soil and amendment as well as plant uptake (Smith, 2009). Treatment technology and processing of organic wastes have increased during recent years, and land application as a waste management strategy has become increasingly popular (Park *et al.*, 2011). As a result, there is a strong need to monitor the quality and hence the concentrations of different TEs in organic wastes. Examples of TE concentrations in animal manures, biosolids and municipal organic wastes, representing the major sources of TE inputs into soil, are given in Table A1 (Appendix).

2.2.1. Animal manures

The application of animal manures has become a major source of TE inputs into soil, and repeated applications can result in an accumulation, especially of Zn, Cu and Ni (Park *et al.*, 2011). The use of TEs such as Fe, Mn, As, Se and Co as animal dietary supplement has also resulted in an enrichment of these TEs in organic waste streams. However, the ultimate concentration of TEs in manures depend on several chemical, biological and physical production factors, e.g. age and size of animals, manure collection or storage and handling of the manures (Park *et al.*, 2011). In this context, a repeated application of pig slurry has resulted in soil Cu and Zn values of 183 kg and 266 kg per ha, respectively (Martinez & Peu, 2000). Poultry manure amendments in addition may contain high levels of Cd and As, but also B (Table A1, Appendix), which can cause accumulation in the long term (Wuana & Okieimen, 2011) or enter the food chain, when taken up by edible plants (Jinadasa *et al.*, 1997). In New Zealand, Cd accumulation in manure from sheep and cattle has led to restrictions and export barriers for meat to overseas markets (Loganathan *et al.*, 2008).

2.2.2. Biosolids

Urban wastewater treatment plants create large quantities of biosolids. Depending on its origin, biosolids can carry high loads of TEs, including As, Cd, Cr, Co, Hg, Mn, Ni, Pb, Se and Zn (Park *et al.*, 2011). Because of physical-chemical processes involved in wastewater treatment, TEs that are existent in the wastewater accumulate in the generated biosolids (Bai *et al.*, 2012). To reduce the amounts of fertiliser for agriculture, but also to rebuild degraded land, land application of biosolids has become attractive, since biosolids contain high concentrations of nutrients, especially N and P (Bai *et al.*, 2012). The long-term disposal of biosolids to landfill will become prohibitively expensive. In the United States, some 5.6 million dry tonnes of biosolids is produced with around 50% reused for land application and agricultural purposes (Wuana & Okieimen, 2011). Australia produces more than 175 000 dry tonnes of biosolids per year, most are applied to agricultural land and incorporated into the soil (McLaughlin *et al.*, 2000). In China, more than 5 million dry tonnes of biosolids are produced annually, with land application as the most cost-effective option of disposal (Tang & Zhao, 2005). New Zealand produces a yearly amount of around 1.5–2 million wet metric tonnes of biosolids with varying moisture contents, whereas 90% is disposed into landfill, however striving towards a higher percentage of biosolids reuse (Goven & Langer, 2009). Recent studies in New Zealand have shown increased concentrations of Cd, Ni and Zn in drainage water and soils after biosolids application to soil-grassland systems (Keller *et al.*, 2002; Speir *et al.*, 2007) and undisturbed soil (McLaren *et al.*, 2004), illustrating a strong need to monitor TE concentrations in biosolids subject to soil application.

2.2.3. Municipal solid wastes and composts

TEs are present in many household products, including batteries, body-care products, pesticides and medicines, and are present in many plastics, ink cartridges and paints (Bardos, 2004). Consequently, when transferred and composted, municipal solid waste represent a major source for TEs. Zinc, Cu,

Ni, Cd, Pb, Cr and Hg are of major concern (Smith, 2009). However there are differences in TE concentrations between different types of municipal solid wastes, depending on their origin, separation processes and treatments (Amlinger *et al.*, 2004; Bardos, 2004). Mechanically segregated composts in general tend to contain higher concentrations of TEs compared to source segregated ones, nevertheless due to advancing technology, both types can comply with e.g. UK limits (Smith, 2009). Compost from municipal solid wastes has similar properties to biosolids, and is treated and utilised similarly when in terms of land application. With the exception of Pb, in mechanically segregated composts, TE concentrations are likely to be 30 – 50% lower than in biosolids (Smith, 2009), whereas the Pb content can be similar or even up to 80% higher. Recent research however has shown that municipal solid wastes have a high potential for TE sorption, hence limiting their solubility and bioavailability in soil. Lead in this context has been shown being the most strongly bound element whereas Ni the weakest; intermediate sorption characteristics have been shown for Zn, Cu and Cd (Smith, 2009).

3. AIMS AND APPROACH

3.1. Justification for nitrogen (N) loading rates in different application scenarios

Current guidelines recommend that biosolids are applied in accordance with the agronomic N needs of crops and assumes all N will eventually become mineralised and hence have potential for leaching as nitrate (Barbarick *et al.*, 2010; Lagae *et al.*, 2009; Sullivan *et al.*, 2009). Currently there is no regulation of biosolids P application, but because of concerns of effects of repeated applications on soil P and P loss to surface waters, a similar approach has been considered as for fertiliser P and manure P application (Lu *et al.*, 2012).

When using biosolids to rebuild degraded land or low-fertility soil, biosolids are often applied at greater than agronomic rates to build up soil organic matter and improve soil fertility. The required high application rates can exceed guideline values for nutrients, which were set to avoid excessive leaching or run off into lakes and streams causing eutrophication (Tian *et al.*, 2006). The *Organic Materials Guidelines* should take into account these application scenarios with recommendations for the safe application of biosolids. However, the impact and accumulation of TEs after application to either agricultural or degraded land has to be assessed.

3.1.1. Biosolids application in a continual application scenario

Biosolids when applied at agronomic rates can increase grain yields compared to conventional N fertilization (Koenig *et al.*, 2011; Sullivan *et al.*, 2009), but high rates can also lead to yield loss through waterlogging (Mantovi *et al.*, 2005) or moisture stress (Cogger *et al.*, 1998). Within the European Union, specific directives have been established to ensure a correct biowaste application management to avoid excessive run-off and leaching of nutrients into surface water and groundwater (Park *et al.*, 2011). A continual application of biosolids can increase the soil N supply, which requires an adaption of application rates to avoid N loss in the long term (Cogger *et al.*, 2013; Hernández *et al.*, 1991; Moss *et al.*, 2002; Uggetti *et al.*, 2012; Walter *et al.*, 2000). Active soil testing would provide valuable information for a sustainable management of biosolids at sites with repeated applications, whereas determining residual soil nitrate in the fall will help guide N application rates at long-term application sites

In New Zealand, an application rate of 200 kg N per ha per year is recommended for pasture. However, this rate is based on plant available N, and as already stated in the current *Guidelines for the Safe Application of Biosolids to Land in New Zealand* (2003) (NZWWA, 2003), application rates should be based on site-specific assessments including climate, soil characteristics, mineralisation rates and agronomic N requirements of the crops. A recent study suggested that high agronomic biosolids application rates of between 450 and 600 kg N per ha every two years have resulted in more vigorous vegetative plant growth, which probably led to more rapid soil moisture depletion hence depressing grain yields (Cogger *et al.*, 2013). Effects like this should be taken into account when averaging application rates over several years.

However, for a continuous biosolids application to agricultural productive land, a rate of 200 kg N per ha per year still represents an adequate guideline value. According to decreasing mineralization rates after the first year of application, it is unlikely that the total amount of available (mineralized) N each year, including plant available N already present in soil, will add up to cause excessive N leaching.

3.1.2. *Biosolids applications to rebuild a degraded soil*

Depending on its composition and treatment, biosolids can contain high concentrations of nutrients. A soil application of biosolids can restore organic matter and provide nitrogen, phosphorus, and sulphur (Uggetti *et al.*, 2012). Several studies have demonstrated that biosolids can reclaim degraded lands (Dere *et al.*, 2012; Mbakwe *et al.*, 2013; Meyer *et al.*, 2001; Oladeji *et al.*, 2013; Speir *et al.*, 2003; Stehouwer *et al.*, 2006). Large amounts of organic material added via biosolids have been found to promote topsoil development, increase water holding capacity and stimulate microbial activity and nutrient cycling (Stehouwer *et al.*, 2006). Most N that exists in biosolids is present in organic form, hence unavailable for plant uptake and not subject to leaching (Pu *et al.*, 2008). To minimise N leaching and runoff, N mineralisation rates need to be estimated.

Biosolids application for reclamation purposes often only requires one single application. After biosolids application to soil, between 15 and 55% of the organic N can be mineralised during the first year after application (Adegbidi & Briggs, 2003; Binder *et al.*, 2002; Eldridge *et al.*, 2008; Mendoza *et al.*, 2006; Robinson *et al.*, 2002; Vieira *et al.*, 2005). Degraded lands are characterised by a loss of soil organic matter, soil structure and nutrient availability, hence a biosolids application rate based on 200 kg total N per ha won't provide enough N_{min} to ensure proper plant growth. Conversely, high application rates of between 50 – 100 tons of biosolids (2500 – 5000 kg total N assuming a biosolids N content of 5%) per ha have been proven suitable for re-vegetation and long-term plant growth (Hearing *et al.*, 2000), but excessive N can be lost from these systems via leaching (Dere *et al.*, 2012; Stehouwer *et al.*, 2006)

However, mineralisation rates are highly dependent on the composition of biosolids on the one hand, and the soil properties on the other hand (Pu *et al.*, 2012), making it difficult to determine the appropriate amount of biosolids to be applied unless they are assessed on a case-by-case basis. Generally, in the first year after application mineralization rates are 30% for aerobically digested biosolids, 20% for anaerobically digested biosolids and 10% for composted biosolids, these figures may provide a good starting point for further calculations (Hearing *et al.*, 2000). Since the biosolids total N content varies from 1% to 6% depending on its origin and treatment (NZWWA, 2003), an application of 50 tons of biosolids per ha could result in either 125 kg N_{min} per ha or 750 kg N_{min} per ha, assuming a mineralisation rate of 25% within 12 months after application. Runoff and loss of N via leaching is likely in the latter, but negligible in the first case.

For a more appropriate and safe application of biosolids for reclamation purposes the revised guidelines could allow one-off applications based on a biosolids N_{min} value of 150 kg N_{min} per ha. Further applications can be made with a time-lag of three years and a biosolids application rate of 150 kg N_{min} less N_{min} content measured in soil prior to application. Guidelines should be flexible enough to allow assessments on a case-by-case basis.

3.2. **Trace elements in biowastes**

The TE concentrations in biowastes have been limited to guarantee its safe application to land. A policy framework for the beneficial reuse of biowastes in New Zealand has been released with the *Guidelines for the Safe Application of Biosolids to Land in New Zealand (2003)* (NZWWA, 2003). However, since there is growing interest in increasing the recycling of organic wastes on the one hand while simultaneously preventing TE accumulation in soil on the other hand, recent literature and revised international standards have to be taken into account to review *Guidelines for the Safe Application of Biosolids to Land in New Zealand (2003)*. The actual level of contamination and its risk to the food chain is strongly related to the bioavailability of TEs in soils and plants, which depends on factors like soil pH, plant species and their cultivars, growth stage, biosolids source, soil condition and the chemistry of the element (Warman & Termeer, 2005).

TEs in biosolids of most concern are Cr, Cu and Zn, Pb, Ni, Cd. Boron, Mn, Se, As and Hg can also be present in high concentrations, depending on the origin and treatment of the biosolids (Park *et al.*, 2011; Silveira *et al.*, 2003). TEs can be grouped into essential and nonessential for humans/plants/animals, whereas Cr, Cu, Zn, B, Se and Mn are assigned to the former, and Pb, Ni, Cd, As and Hg to the latter group. Nonessential TEs can cause major health problems, but essential TEs can also be potentially toxic at high concentrations (Nicholson *et al.*, 2003), hence limits in biowastes for soil application purposes are necessary to prevent high amounts of TEs accumulating and entering the food chain.

3.2.1. Organic wastes as a source for essential human trace elements

Zinc (Zn)

Zinc can be present in high concentrations in biosolids and composts (Table A1, Appendix). It is relatively labile and is readily transferred to plant tissues (Smith, 2009). Recent research has shown the use of biosolids application to increase Zn concentration in plants to reduce animal deficiencies (Anderson *et al.*, 2012). At high concentrations however, Zn can also influence soil activity by negatively influencing the activity of microorganisms and earthworms hence slowing down organic matter degradation (Wuana & Okieimen, 2011), and an accumulation in plants has been reported to cause rolling of young leaves, death of leaf tips and chlorosis (Rout & Das, 2009). Generally Zn is important in many biological functions, but recent studies increasingly show free ionic Zn (Zn^{2+}) as more biologically toxic than traditionally presumed (Plum *et al.*, 2010). Due to its high mobility, but also its potential to accumulate in soil in the long term, a threshold should be included for a safe biosolids application to land to prevent accumulation in soil and plant damage.

Chromium (Cr)

Chromium was proposed as an essential element in mammals and humans around fifty years ago, with a role in maintaining proper carbohydrate and lipid metabolism (Pechova & Pavlata, 2007). In high concentrations it is associated with allergic dermatitis in humans (Wuana & Okieimen, 2011). In soil and soil amendments, Cr is characterised as an element with extremely low bioavailability (Smith, 2009), hence does not accumulate in above ground plant parts or the food chain. However, it can accumulate in soil where it can be toxic to plants as chromate (Cr^{6+}), or can be transported into surface waters by runoff, or leach into groundwater (Epstein, 2002); (Wuana & Okieimen, 2011). Therefore, a guideline value is necessary to prevent phytotoxicity and contamination of waterways.

Copper (Cu)

Copper is an essential micronutrient required for growth-related processes in plants, animals and humans. Its availability is limited in biosolids and biosolids amended soil due to the extent of its complexation, particularly with organic matter (Smith, 2009). Most Cu that is introduced is quickly stabilized and does not pose any risk to the environment. It is therefore of less concern regarding land application of organic wastes (Wuana & Okieimen, 2011). Plant uptake is well regulated, hence concentrations in plant tissues and the risk of bioaccumulation in the food chain is usually low (Smith, 2009). Copper in high doses can cause anaemia, liver and kidney damage, and stomach and intestinal irritation (Wuana & Okieimen, 2011). A Cu limit in biosolids for land application is necessary to protect the ecosystem health.

Manganese (Mn)

High amounts of Manganese (Mn) may be added to soil with organic wastes, especially with the application of manure and sewage sludge (Table A1, Appendix). Mn is known as an essential TE, but can become toxic when present in excess (Millaleo *et al.*, 2010). In plants, Mn toxicity may lead to biomass reduction or chlorotic leaves, but due to different tolerance mechanisms, individual plant species may respond with toxicity symptoms earlier than others (Millaleo *et al.*, 2010). In general, Mn toxicity mainly occurs in acid soils and under water logging. Recent studies have shown Mn toxicity to be strongly dependent on soil pH, hence proposed soil guideline limits between 500 and 2500 mg per kg according to the pH (Hernandez-Soriano *et al.*, 2012). The concentration of Mn can be monitored so as not to exceed soil guideline values, rather than implementing Mn thresholds for biowastes.

Boron (B)

Boron is an essential TE required in small concentrations, usually detected in soil from 2 to 200 mg B per kg (Diana, 2006). However, the range between B deficiency and toxicity is comparatively small, and plant toxicity has been shown when soil concentrations increase above 2.5 mg per kg (Goldberg, 1997; Robinson *et al.*, 2007). B is mobile and does not accumulate in soil to any great extent; however, depending on its origin, certain biowastes may contain high B concentrations (Table A1, Appendix; (Park *et al.*, 2011), potentially toxic to plants when applied at high rates. Generally in NZ soil, boron concentrations are known to be more deficient rather than toxic (Sherrell, 1983), this is because boron readily leaches in our high-rainfall climate. We do not recommend that boron concentrations be regulated in biowastes or soil where biowastes may be applied.

Selenium (Se)

Selenium is increasingly becoming an environmental concern, and the gap between deficiency and toxicity levels in animals and humans is narrow. Selenate-Se is soluble and highly mobile, hence liable to leaching and plant uptake (Dhillon & Dhillon, 2003). Organic wastes, especially biosolids can carry higher concentrations of Se (Table A1, Appendix), but absorption and accumulation of biosolids-applied Se by plants strongly depends on soil characteristics as well as the plant species itself (Dhillon & Dhillon, 2003). However, Se in New Zealand should not pose problems because of generally low concentrations in soil (Sheck *et al.*, 2010), hence guideline concentrations do not necessarily have to be implemented in a new organic materials guideline.

3.2.2. *Nonessential trace elements applied to soil with biosolids*

Lead (Pb)

Lead is a non-essential element for plants and humans, and can be toxic to people if ingested in large amounts. Usually concentrations in biosolids and biosolids amended soil are low. Due to a limited plant uptake the soil-plant barrier means that generally Pb concentrations in plant tissues are low and human food chain impacts are not a concern (Smith, 2009). Lead is mostly applied with biosolids and composts, where it is bound in stable forms that have low availability (Amir *et al.*, 2005; Zheng *et al.*, 2004). Although it is possible that some Pb is taken up by plants if soil concentrations are high, studies have shown Pb does not readily accumulate in the fruiting parts of vegetable and crops (Wuana & Okieimen, 2011). Even long term application with high loads of municipal solid waste – composts have shown only limited mobility of Pb into crops (Gigliotti *et al.*, 1996). In South Australia, lead is proposed to be no longer regulated in biosolids applications because concentrations in biosolids do not represent a risk to human health (ANZBP, 2009). However, the most serious source of exposure to soil Pb is through direct ingestion, hence limits are required to prevent toxic concentrations endangering human health via the consumption of root crops or leafy vegetables, where eating of soil is a concern (Wuana & Okieimen, 2011).

Mercury (Hg)

Soil contamination with Hg has led to environmental concerns. Mercury is a highly toxic and non-essential element that is regarded as an environmental pollutant because of its toxicity, mobility, and long residence time in the atmosphere (Pedron *et al.*, 2013; Wang *et al.*, 2005). It can be readily taken up by plants and accumulate in the food chain, but can also directly affect plant growth, yield production and nutrient uptake if present in toxic concentrations (Patra & Sharma, 2000). Including ceiling concentrations in biosolids for soil application is important to prevent Hg accumulation in soil and hence to prevent increasing concentrations in plant products and potential human health impacts.

Cadmium (Cd)

Together with Hg and Pb, Cd is among the big three toxic elements causing environmental concern, with no known essential biological function (Wuana & Okieimen, 2011). Cadmium has similar chemical properties to Zn, hence able to substitute Cd in certain metabolic processes. Zinc is an

essential micronutrient for plants and animals, therefore its substitution by Cd may cause malfunctioning of metabolic processes (Campbell, 2006). High concentrations in soil and plants pose risks to human health through direct consumption of Cd contaminated food products, but also indirect via e.g. soil ingestion by grazing animals (Park *et al.*, 2011). Agricultural inputs such as fertilisers, pesticides or biosolids can increase the total Cd concentration in soils, hence guideline values in soil as well as limits for Cd in soil amendment are required to prevent its accumulation in the environment (Wuana & Okieimen, 2011).

Arsenic (As)

Arsenic is a potentially toxic element, widely distributed in the environment. Arsenic containing compounds have been extensively used in agriculture and forestry, e.g. to control cattle ticks or pests in banana, or to preserve timbers (copper chrome arsenic, CCA) (Wuana & Okieimen, 2011). In soil, As strongly binds to the clay fraction in the form of arsenate, reducing the mobility through soils as well as plant uptake. In its form of arsenite (formed under anaerobic conditions) it is less adsorbed on soil particles, hence As in the soil solution can be phytotoxic to plants (Epstein, 2002). As phytotoxicity protects As entering into the food chain, but guidelines for soil and soil amendments should prevent an accumulation and hence contamination of soils.

Nickel (Ni)

Nickel is a known potentially toxic in soil and routinely monitored in biosolids subject to land application. However, Ni toxicity is rarely reported in practice, and its hazardous role in the food chain or in terrestrial ecosystems is negligible compared to other TEs (Smith, 2009). Nickel concentrations in biosolids and other biowastes have not been shown to be of environmental significance (Speir *et al.*, 2007) hence guideline values in soil amendments are not necessarily required for a safe application of biowaste to land (Smith, 2009).

3.2.3. Necessity of trace element guideline concentrations in biowastes

A review by Smith (2009) regarding the bioavailability and impact of TEs in biowastes showed various types of biowastes, irrespective of their source, contain higher concentrations of TEs compared to the soil background values. Therefore, long-term application will cause TEs to slowly accumulate in soil until soil limits are approached. Several studies have shown an increase of certain TEs after biosolids application to soil. In general little effect has been shown regarding Ni and Cr; but mainly due to their high availability in biosolids, considerable increases in concentrations of Cd, Cu, Pb and Zn has been detected (Gartler *et al.*, 2013; Illera *et al.*, 2000; Simmler *et al.*, 2013). In a long-term field experiment García-Gil *et al.* (2000) showed significant accumulation of Zn and Cu in soils following the application of 80 t per ha per year of municipal solid waste compost for five years.

Copper levels have been increased in agricultural soils due to repeated fertilisers use or the application of fungicides to protect vines, citrus trees, and other fruit crops against fungus diseases (He *et al.*, 2005; Schuler *et al.*, 2008). Certain types of biowastes, especially manures, may contain high concentrations of Cu (Table A1, Appendix), hence when applied to soil, may cause exceedance of soil guideline values.

Cadmium is naturally found in phosphate rock (Mar & Okazaki, 2012), hence to date, it has been continuously applied to agricultural soil with phosphate fertilisers. The New Zealand fertiliser industry has implemented a self-governed strategy to address Cd management in soils, progressively decreased to a current maximum of 280 mg Cd per kg P (MAF, 2009). For a continuous and sustainable application of biowastes in replacement of conventional fertiliser, Cd could be regulated in a similar way, which would not result in higher Cd concentrations in soils compared to the continuous use of phosphate fertiliser.

A similar system to the “Tired Fertiliser Management Strategy” (TFMS (MAF, 2009) could be used for biowaste applications, where soil concentrations are continuously monitored and further applications become more restricted with higher soil TE concentrations. Using mass balances and simple models, the impact of certain TE concentrations in biowastes on the total soil concentration can be assessed to avoid soil guideline exceedances with biowaste application (Table 3). The total TE concentration in soil (TE_{soil}) could be calculated by adding the concentration applied with the

biowaste (TE_{biow}) to the concentration already present in soil ($TE_{i\ soil}$), but reduced by the amount taken up by plants (TE_{plant}) and lost via leaching (TE_{leach}).

$$TE_{soil} = TE_{i\ soil} + TE_{biow} - (TE_{plant} + TE_{leach})$$

4. RECOMMENDATIONS AND CONCLUSIONS

4.1. Revised guideline values for TE contaminants in biowaste for soil application

Currently, biosolids are used in agriculture, forestry, public recreation and rehabilitation of degraded land. In New Zealand, the *Guidelines for the Safe Application of Biosolids to Land in New Zealand* (2003) (NZWWA, 2003) were established to prevent accumulation of TEs and excess N input into ground and surface waters. However, the availability of TEs in soil is highly variable and strongly depends on soil characteristics. Therefore soil concentrations have to be monitored in combination with concentrations in biowastes to prevent soil contaminant concentration limits being reached. Current international limits of TEs in biowastes and soil are summarized in Table 1 and 2, respectively.

Table 1: International guideline concentrations of TEs in biowastes for land application.

values in mg/kg DW	classification	Cadmium Cd	Copper Cu	Nickel Ni	Lead Pb	Zinc Zn	Mercury Hg	Chromium Cr	Arsenic As
Biosolids (New Zealand)	grade a	1	300	60	300	300	1.0	600	20
	grade b	10	1250	135	300	1500	7.5	1500	30
Biosolids (India)	pH < 7	20	1000	300	750	2500		1000	
	pH > 7	40	1750	400	1200	4000		15000	
Sewage sludges (China)	pH < 6.5	5	800	100	300	2000	5.0	600	75
	pH ≥ 6.5	20	1500	200	1000	3000	15.0	1000	75
Compost (Canada)	class A	3	100		150	500			
	class B	20	757		500	1850			
Biosolids (South Australia)	grade C	20	2500			2500		1 (Cr 6+)	
Biosolids (USA)	grade A	39	1500	420	300	2800	17.0	1200	41
Biosolids (EU)	grade 1	20	1000	300	750	2500	16.0		

Table 2: International soil guidelines for TE contaminants of environmental concern.

values in mg/kg DW	soil properties	Cadmium Cd	Copper Cu	Nickel Ni	Lead Pb	Zinc Zn	Mercury Hg	Chromium Cr	Arsenic As
New Zealand		1.0	100	60	300	300	1.0	600	20
Canada		1.4	63	50	70	200	6.6	64	12
Germany	clay	1.5	60	70	100	200	1.0	100	
	silt	1.0	40	50	70	150	0.5	60	
	sand	0.4	20	15	40	60	0.1	30	
Austria		1.0	100	60	100	300	1.0	100	20
France		2.0	100	50	100	300	1.0	150	
Switzerland		0.8	40	50	50	150	0.5	50	
India			100	60	100	300		50	

The revised guidelines have to take into account the use of biowastes for either a continual soil conditioner, or an amendment that is used in a single application, for example to rebuild a degraded soil. The environmental outcomes of each practice are distinct, and consequently different limits and guideline values are recommended for the most beneficial and safe use of biowastes.

Table 1 shows that NZ's current guideline values for biosolids of grade "B" are similar, or even more conservative, to overseas guidelines. Table 1 also shows that NZ's current guideline values for biosolids of grade "A" are, in many cases, an order of magnitude lower than overseas guidelines. The current guidelines for grade "A" biosolids were developed to allow the continual application of

these materials to land without causing excessive accumulation in soils, grain and livestock products (ANZBP, 2009). However, many, if not most, biosolids in NZ do not meet grade “A” criteria with respect to TEs (MfE, 2005). Moreover, many of these biosolids exceed guideline values for Cu and Zn. These elements can have agronomic benefits when added to NZ soil (Gartler *et al.*, 2013; McLaren *et al.*, 1990).

Rather than protecting soils by setting low guidelines for biosolids TE concentrations guidelines, we propound that the amount of biosolids added to soil should be determined on the soil’s TE concentration. We suggest that the NZ soil guidelines that are currently under development, be used as threshold values that should not be exceeded by biosolids addition.

Comparing the current soil guideline values for biosolids with internationally-recognised guideline values (Table 2) reveals that for some TEs, the New Zealand values are considerably higher. These international-values have been based on decades of research into the effect of TEs on soil function. Therefore, the new soil TE guidelines that NZ eventually adopts may well be lower than the current biosolids guidelines. Here, we aim to show that even if these soil guidelines are lowered, this will not prohibit biosolids addition to soil with respect to their TE concentration. Table 2 shows that, even using conservative guideline values, consistent with internationally-recognised guideline values, at least 125 tonnes of biosolids at the upper limit for grade “B” could be applied before the guideline values are met for Cr.

Table 3: The minimum amount of biosolids that could be applied, over several years (i.e. the biosolids/ soil ratio is small), without breaching even “precautionary” soil guideline values. These calculations assume that biosolids are mixed into the top 30 cm of soil (over several years), a soil density of 1.3 g/cm³, and negligible leaching or removal in crops.

Element	Nominal agricultural soil	Precautionary soil guidelines (following EU example)	Mass of biosolids (tonnes / ha) that can be applied before limit reached	
			Biosolids at grade “A” limit	Biosolids at grade “B” limit
Cd**	0.43	1	2223	222
Cu*	15	60	585	140
Ni*	12	50	2470	1098
Pb*	12	50	494	494
Zn*	68	150	1066	213
Cr*	27	75	312	125
As*	4.1	20	3101	2067
Hg***	0.1	0.5	1560	208

* Reiser et al. (2014). Journal of Environmental Quality

** Taylor M.D., Ltd M.W.-L.R.N.Z. (2007) Soil maps of cadmium in New Zealand Ministry of Agriculture and Forestry.

*** Estimated

4.2. Recommendations for a revised biowaste application guideline

This report considers that biowastes can be used either as a continual soil conditioner, or an amendment that is used in a single application, for example to rebuild a degraded soil. The environmental outcomes of each practice are distinct and consequently different values will be given for each practice.

Nitrogen:

- a. For the continual application of biosolids, nitrogen concentrations should not exceed current regulatory guidelines of 200 kg / ha / yr or 400 kg / ha every two years, based on evidence that the organic nitrogen present in biosolids is eventually mineralised.

- b. When using biosolids to rebuild a degraded soil, the nitrogen limit should be based on mineral nitrogen (e.g. 150 kg / ha), because the organic N given in a single application will not mineralise at a rate sufficient to cause excess nitrate leaching.

Trace Elements:

We propose the abandonment of metal concentrations to categorize biowastes as either "A" and "B". The guidelines for all biowastes will be based around the old "B" limits. This enables the reuse of a much greater number of biowastes in NZ, while preventing the soil disposal of toxic waste. These former "B" guidelines are consistent with overseas guidelines for biowastes. We propose that biosolids can be added *ad lib* with respect to TEs as long as the soil TE concentration stay's within NZ's soil guideline values, which are currently under development. We do not assume to make a suggestion on what these are.

4.3. Possible wastes that may be included in a new guideline

To reduce and avoid prohibitive costs for landfill, an increasing effort is made with recycling waste material. However, treatment technology and procession of organic wastes have increased during recent years, and land application as waste management strategy has become increasingly popular (Park *et al.*, 2011).

The application of animal manures has become a major source of TE input to soil, and repeated applications easily result in an accumulation, especially of Zn, Cu and Ni (Park *et al.*, 2011). The uses of TEs like Fe, Mn, As, Se and Co as animal dietary supplement additionally has resulted in an enrichment of these TEs in organic waste streams (Park *et al.*, 2011).

TEs are present in many household products, including batteries, bodycare products, pesticides and medicines, and are present in many plastics, ink cartridges and paints (Bardos, 2004). Consequently, when transferred and composted, municipal solid waste represents a major source of TEs, Zn, Cu, Ni, Cd, Pb, Cr and Hg are of major concern (Smith, 2009). However there is a huge difference in TE concentrations between different types of municipal solid wastes, depending on its origin, separation processes and treatments (Amlinger *et al.*, 2004; Bardos, 2004).

The majority of medical waste worldwide is incinerated in a high temperature oxidation process, resulting in a significant reduction of waste volume and weight, but producing incinerator ash (Shams *et al.*, 2012). Different types of ash (bottom ash, fly ash) can contain high concentrations of TEs as well as organic compounds. Although bottom ash is generally considered to be safer than fly ash, a recent study showed high concentrations of TEs in bottom ash (Shams *et al.*, 2012). Proper management is required to avoid serious environmental problems (Shams *et al.*, 2012). According to our definition, biowaste should have an organic carbon content of >30%, thus incinerated wastes or other ash would fall outside these guidelines containing <30% organic carbon.

We suggest that pulp and paper be considered under the nitrogen and TE guidelines for other biosolids. We suggest that, given the high C:N ratio, pulp and paper waste may be beneficially blended with other wastes such as biosolids to further improve soil fertility whilst mitigating nitrate leaching.

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7. APPENDIX

Examples from referenced heavy metal concentrations in different types of manure, municipal sewage sludge and municipal solid waste (adapted and extended from Park et al., 2011)

value-DB-RESes in mg/kg DW	Arsenic As	Boron B	Cadmium Cd	Cobalt Co	Chromium Cr	Copper Cu	Mercury Hg	Manganese Mn	Molybdenum Mo	Nickel Ni	Lead Pb	Selenium Se	Zinc Zn
Cattle manure													
Dairy manure					15.0	7		372		9.0	9		67
Dairy liquid and solid manure	1.3	8.1	0.2			139			2.5	0.8	2	3.0	191
Cow dung						200		700					800
Cow manure	6.8		0.7	2.2		18	<0.4	172		9.6	8		
Cattle manure (composted)	5.2		0.4	3.6	14.4		<0.4	357		8.7	5	0.5	164
Feed lot manure						17		149					6480
Dairy cattle FYM	1.6		0.4		5.3	38				3.7	4		153
Dairy cattle slurry	1.4		0.3		5.6	62				5.4	6		209
Beef cattle FYM	0.8		0.1		1.4	16				2.0	2		81
Beef cattle slurry	2.6		0.3		4.7	33				6.4	7		133
Poultry manure													
Poultry dropping						400		1800					2300
Broiler litter	34.6		4.9		9.9	6		501		2.5	1.2	1.2	743
Broiler / turkey litter	9.0		0.4		17.7	97				5.4	4		378
Layer manure	0.5		1.1		4.6	65				7.1	8		459
Poultry litter	43.0	51.0	3.0	6.0		748		956	6.0	15.0	11		718
Deep-pit poultry litter		19.0	2.0	8.0	6.0	19		271		14.0	13		252
Poultry manure		390.0	0.5		7.3	54		465	7.7	7.0	2		550
Swine manure													
Swine manure			0.3		33.0	1338		869		12.4	14		1440
Swine dung						1000		2100					2900
Cu-enriched swine manure		17.8				1279		197					231
Swine FYM	0.9		0.4		2.0	374				7.5	3		431
Swine slurry	1.7		0.3		2.8	351				10.4	2		575
Sewage sludge													
Sewage sludge (Athens, Greece)	5.0		11.2		75.1	55		1248		53.4	2	1.2	294
Urban compost (unspec.)			0.5		71.0	119		214		15.0			
Sewage sludge (unspec.)			11.4		645.0	870		497		475.0	226		1788
Sewage sludge (Denver, USA)	8.1		26.0	7.1	280.0	816	7.8	220	84.9		950	4.6	1672
City sewage sludge (unspec.)	14.3		104.0	9.6	1441.0	1346	8.6	194	14.3		1832	3.1	2132
Sewage sludge (Austin, USA)	9.4		3.3	4.1	106.0	300	1.5	430		36.7	87	2.6	563
Sewage sludge (Milwaukee, USA)			7.2	4.1	2940.0		1.1	142		31.2	130	1.0	450
Anaerobic sewage sludge (unspec.)			4.4		5.1	709		129		5.3	67		407
Municipal solid waste													
Fresh municipal solid waste			6.0		16.0	139		816		25.0	216		2677
Degraded waste			3.0		53.0	173		643		21.0	420		1658
Municipal solid waste			9.0		55.0		1.2				330		
Green waste			0.1		20.0	37					87		214
Mixed refuse compost			5.5		5.5	274					513		1510
Wet waste from kitchen			0.1		0.1	14	0.1			1.2	8		

6 ORGANIC CONTAMINANTS REVIEW

This section is available as separate reports.

6.1 CIBR PUBLICATION 012 ORGANIC CONTAMINANTS REVIEW AUGUST 2014

The first report is: CIBR Publication 012 Organic Contaminants Review August 2014 which updates section 2 organics information which is available as a separate download [here](#). This document

- ◆ Summarises existing knowledge on organic contaminants in organic wastes;
- ◆ Reviews the justification for the inclusion of the Guidelines list of organics; and
- ◆ Determines if other organic contaminants of concern should be included.

Reviews the existing allowable concentrations for biosolids and recommends any new limits with support logic.

6.2 CIBR LETTER REPORT DATED 7TH AUGUST 2017

Following public consultation of the first public draft documents a subsequent review of selected queries was provided by Dr Grant Northcott, CIBR which is available as a separate download [here](#). The letter report responds to:

- ◆ A justification for changing the list of organic contaminants;
- ◆ An updated list of organic contaminants for monitoring;
- ◆ Recommended product limits for the new list of organic contaminants; and
- ◆ Recommended methodologies for their analysis.

6.3 COMMENTS ON GLYPHOSATE AND TRICLOSAN

Emailed comments were also received from Dr Northcott in response to queries on whether Glyphosate and Triclosan should be added to the list of emerging organic contaminants with concentration limits. A summary of emails dated 26 October 2017 and 2 November 2017 are provided below:-

I have some reservations regarding the rationale for including glyphosate and triclosan in the list of organic contaminants in biosolids.

With respect to glyphosate the principal source of glyphosate in soil across New Zealand is agricultural and horticultural use. Currently agricultural use of glyphosate is outstripping all others as it's one of the most widely used herbicides for the production of supplementary feed crops for dairy cows. Horticulture use has increased with expansion of this sector, but nowhere near the extent that it has in agriculture. There's a reasonable amount of urban use in the mix, but the largest annual usage in NZ is by the agricultural sector.

Therefore it's no surprise glyphosate has become a ubiquitous soil contaminant across NZ, nor that the concentration of glyphosate in soil has outstripped that of all other pesticides. The prevalence and high concentration of glyphosate in agricultural soils in New Zealand provides a reservoir of glyphosate that is transported with fine soil particles into nearby aquatic waterways where they accumulate as sediment deposits in waterways. This sediment load is itself transported

downstream within waterways to deposit in estuaries. Hence, the presence and prevalence of glyphosate in freshwater and marine sediments in New Zealand.

In comparison to the input of glyphosate from agricultural activities in New Zealand soils it is difficult to see how biosolids would represent anything other than a minor contribution to the total soil burden of glyphosate.

The 2004 CDRP study demonstrated that glyphosate was not a significant contaminant in NZ biosolids back when the study was completed. I expect this remains the case, unless New Zealanders have altered their behaviour and dispose of glyphosate formulations down the toilet. I suspect not, as most consumers will use up their bottle of glyphosate formulation and dispose of the empty bottle via rubbish collection

In summary I don't think Regional Councils and MfE etc should be concerned about glyphosate in biosolids impacting the health and function of soil. However they should be very concerned about the magnitude and increasing use of glyphosate in the agricultural sector and the impact this could be having on terrestrial and aquatic ecosystems.

Triclosan is a different story, as other than its use in medical facilities it's principally used in personal care products and therefore is a common contaminant in WWTPs and biosolids. However, public attitude to triclosan has changed and consumers around the world are demanding its removal from many products. The use of triclosan as an ingredient in personal care products, toys, and other consumer products is being progressively banned by countries around the world. The main use of triclosan in New Zealand at this time is in some types of toothpastes, principally those marketed as anti-bacterial or with enhanced plaque control. To the best of my knowledge Triclosan has largely been removed from liquid soaps, shampoos, body washes etc. that are sold on the New Zealand market.

The concentration of triclosan in New Zealand biosolids will therefore continue to decrease until it reaches a steady state that is consistent with the sale and use of toothpastes containing triclosan. Given all the negative publicity around the use of triclosan in personal care products I can't see it surviving for too much longer in toothpaste, or if it does it's likely it will only be in specific types available from a dentist. The use of products containing Triclosan in hospitals is likely to continue but this represents a relatively minor contribution to current use.

Further information will be forthcoming from CIBR research regarding the ecotoxicological impact of triclosan in soil. A manuscript on the impact of triclosan on earthworms is being developed for publication. There's also another on degradation of triclosan in two New Zealand soils, and another follow up paper on the combined impact of triclosan and heavy metals in soil. So over the next year there will be more New Zealand specific data available on the impact of triclosan in New Zealand soils.

So we need to decide if it's worthwhile including triclosan for inclusion in the next revision of this Guideline. One way to address this issue could be to include a statement that the use of triclosan is expected to continue decreasing over the next five years as it's progressively banned and removed from products, and therefore the concentration in New Zealand biosolids will also continue to decrease. The decision whether to include triclosan as an organic contaminant could be addressed in the next guideline revision following a review of its continued use in New Zealand, the confirmation of residual concentrations in New Zealand biosolids, and the outcomes from CIBR research on the impact of triclosan in New Zealand soils.

This advice lead to the statement in the Guide that Increased use of glyphosate in the agricultural and horticultural sectors is of growing concern as has been that of Triclosan in personal care products, although its use is reducing. Further investigation of their concentrations and environmental effects is recommended with consideration for a product concentration limit within the next 5 yearly review of this Guide.



Centre for Integrated Biowaste Research

Organic Materials Guidelines – Organic Contaminants Review

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Centre for Integrated Biowaste Research

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Centre for Integrated Biowaste Research

'Organic Materials Guidelines – Organic Contaminants Review

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EXECUTIVE SUMMARY

The Ministry for the Environment New Zealand Water and Wastewater Association (2003) Guidelines for the Safe Application of Biosolids to Land in New Zealand are designed to safeguard the life-supporting capacity of soils, promote the responsible use of biosolids, protect public health and the environment and minimise risk to the New Zealand economy.

There is a strong perception of risk within the wider community when considering land application or reuse of biosolids. There are concerns about the range of contaminants that those wastes could contain and the uncertainty about the potential health effects and economic consequences. This report critically reviews the pertinence of the organic contaminants that are incorporated in the Guidelines document to recommend amendments that reflect the current level of knowledge to minimise any potential risk associated with the land application of biosolids and other biowastes.

Below are the recommendations for emerging organic contaminants (EOCs) that could form part of the new Organic Materials Guidelines:

- The organic contaminants listed in Table 4.2 of the NZ guidelines can be considered as obsolete in view of the on-going research findings on the sources and fate of POPs in New Zealand;
- Alternatively, new contaminants should be considered for inclusion in view of recent findings on the levels and risk potential of EOCs in biosolids. Based on local and international literature, EOC classes should include endocrine disruptors (e.g. steroids, nonylphenols), flame retardants (e.g. HBCD and selected PDBEs), antimicrobial agent (e.g. triclosan and ciprofloxacin) and pharmaceuticals (e.g. carbamazepine, diclofenac); persistent herbicide (clopyralid); cleaning agent (LAS);
- At this stage, there is not enough information to derive New Zealand specific limits but interim values could be used as per Table 4;
- Other biowastes should be included in the revised guidelines and soil limits should be derived for the specific residue contaminants. The selection of contaminants should be risk-based, i.e. involve estimations of both exposure and effect;
- The revised Guidelines should be based on a flexible and responsive framework to incorporate new and relevant scientific knowledge to facilitate the ongoing acceptance and adoption of the beneficial use of biowastes in NZ. The framework should also facilitate incorporation of social, cultural and community input as the acceptance of the practise will depend on the relevance and risk perception of the various contaminants.

Introduction and context

The *Guidelines for the Safe application of Biosolids to Land in New Zealand* was published in 2003 and a review is conducted to amend the document according to the latest information available in the literature. This report reviews the component of the Guidelines relating to organic contaminants to assess the validity of suggested threshold values and the relevance of chemical targets. In the last 10 years, there has been significant progress in research on organic contaminants in biosolids and their potential risks. This report critically reviews the pertinence of the organic contaminants that are incorporated in the current Guidelines document and recommend amendments that reflect the current level of knowledge to minimise any potential risk associated with the land application of biosolids and other biowastes. There is an emphasis on a group of contaminants referred to as emerging organic contaminants (EOCs). The US Geological Survey has defined an EOC as “any synthetic or naturally occurring chemical or any microorganism that is not commonly monitored in the environment but has the potential to enter the environment and cause known or suspected adverse ecological and (or) human health effects. In some cases, release of emerging chemical or microbial contaminants to the environment has likely occurred for a long time, but may not have been recognised until new detection methods were developed. In other cases, new sources of emerging contaminants can be created through the synthesis of new chemicals or changes in use and disposal of existing chemicals (<http://toxics.usgs.gov/regional/emc/>).

Aims and Approach

The aims of this report were to:

1. Summarise existing knowledge on organic contaminants in organic wastes relative to the current *Guidelines for the Safe and Application of Biosolids to Land in New Zealand* (2003) (Table 4.2).
2. Review the justification for the inclusion of the following organics: DDT/DDD/DDE; Aldrin; Dieldrin; Chlordane; Heptachlor & Heptachlor epoxide; Hexachlorobenzene (HCB); Hexachlorocyclohexane (Lindane); Benzene hexachloride (BHC); Total polychlorinated biphenyls (PCBs); Total dioxin TEQ (cf Table 4.2 in the Biosolids Guidelines). Provide recommendations for which organic contaminants should and should not be in a new guideline with supporting logic.
3. Determine if other organic wastes contain additional organic contaminants of concern that should be included in a new guideline.
4. Review the allowable concentrations of organic contaminants in biosolids (Table 4.2. in current Biosolids Guidelines); and provide recommendations for any new limits for waste that will not cause waste-amended soil to approach the soil contaminant limits (using the current soil limits in Table 4.2 noting that these might change under the new Soil Health Indicators Envirolink Project).
5. Provide recommendations for the above items 1-4 with supporting logic.

Summary of Existing Knowledge

The *Guidelines for the Safe Application of Biosolids to Land in New Zealand* (New Zealand Water Wastes Association 2003) was written with the purpose to:

- Safeguard the life-supporting capacity of soils;
- Promote the responsible use of biosolids;
- Protect public health and the environment;
- Identify the risks associated with biosolids use and promote best practice for minimising such risks;
- Encourage local authorities to adopt a consistent approach to regulating the application of biosolids to land;
- Create awareness within the community of the benefits and risks of biosolids use;
- Minimise the risk to the economy.

Within these guidelines risks are divided largely into microbiological and chemical categories. This is reflected in the grading system for the biosolids which includes a separate grading for microbiological quality and chemical quality. According to these guidelines biosolids can be awarded 2 levels of microbiological grades (A and B) and 2 levels of organic contaminants grades (a and b). The microbiological risks are dealt with in another Working Group report. As biosolids are likely media to accumulate parts of those products, a recent review of Guidelines commissioned by the ANZ Biosolids Partnership concluded that contaminant levels for each of the grades should be updated in line with up-to-date international, Australian and New Zealand research knowledge (Darvodelsky et al. 2009).

The use of chemicals is a key component in the maintenance of our standard of living in modern society. With nearly two thirds of the world's population living in urban areas, cities concentrate multiple human activities and are major contributors of waste by being concentrators, repositories, and emitters of a myriad of chemicals of anthropogenic origin (Diamond & Hodge 2007). Many chemicals are produced from daily domestic activities such as cooking, cleaning, personal grooming, medical care, and gardening. A study investigating contaminants contained in household solid wastes in the UK identified a number of sources including paint, pet products, pharmaceuticals, household cleaners, motor vehicle waste and printer cartridges (Slack et al. 2007). The focus has been on high production volume (HPVs) chemicals in use in household products for their higher potential to accumulate into the environment. The US National Institutes of Health (NIH) list roughly 2800 compounds in daily (household) use, based on a survey of Material Safety Data Sheets (MSDS) of 7000 household products. HPV chemicals are manufactured in or imported into the United States in amounts equal to or greater than 0.5 million kg per year. An extensive study commissioned by the Water Environment Research Foundation (WERF) looked at household chemicals from a list of 720 HPV compounds identified within eight main activities: 1) auto products, 2) inside the home, 3) pesticides, 4) home maintenance, 5) personal care/use, 6) pet care, 7) arts and crafts, and 8) landscape/yard. From the extensive list of HPV chemicals, a two-tiered ranking approach based on production volumes, environmental relevance, and feasibility for analytical quantification was developed. Tier 1

compounds are classified as consumer product chemicals that can be released in high quantities. Tier 2 are organic compounds that are either frequently used in households or are present in household products. Short lists of 11 Tier 1 and 13 Tier 2 chemicals were identified by WERF for future monitoring and are summarised in Tables 1 and 2.

Table 1. Major emerging organic contaminants associated with household wastes- Tier 1 compounds. From WERF report 2009.

Compound	Application
2,6-Di-t-butyl-p-cresol (BHT)	Skin care, hobby supplies
Dibutyl phthalate	Plasticizer, finish, nail care
Atrazine	Herbicide
Bisphenol A (BPA)	plasticizer, epoxy, glue
Benzophenone	Car wash, facial products
Oxybenzone	Skin care, insect repellent
Triclosan	Antibacterial, soap, lotion
Vanillin	Fragrance, cosmetics, various
o-Phenylphenol	germicide, fungicide
2-Phenoxyethanol	Preservatives, cosmetics, fragrance
Hexabromocyclododecane (HBCD)	Flame retardant

Table 2. Major emerging organic contaminants associated with household wastes- Tier 2 compounds. From WERF report 2009.

Compound	Application
Simazine	Herbicide, anti-algae products
DEET	Insect repellent
Hydrocortisone	Anti-itch cream
Butylated hydroxyanisole (BHA)	Antioxidant, various
3-Indolebutyric acid	Fertilizer
Camphor and menthol	Fragrance, various
2-Methylresorcinol	Hair colour, cosmetics
Isobutylparaben	Preservative, cosmetics, various
Acriflavine	Pesticide
Trifluralin	Herbicide
Propylparaben	Preservative, various

Linear alkylbenzene sulfonate (LAS) and triclocarban were also incorporated in the design as model compounds for their specific characteristics (Table 3). LAS can function as a model for complex mixtures and triclocarban is an emerging contaminant model for which only a limited amount of data is available. Several previously studied pharmaceuticals were also studied as indicator compounds of interest (Table 3).

Table 3. Model emerging organic contaminants associated with household wastes used as model and indicator compounds. From WERF report 2009.

Compound	Application
Model Compounds	
Triclocarban	Antibacterial, soap, deodorant
Linear alkylbenzene sulfonate (LAS)	Surfactant, various
Indicator Compounds	
Primidone	Antiepileptic drug
Phenacetine	Anti-inflammatory drug
Carbamazepine	Antiepileptic drug
2-Naphthol	Industrial chemical
Fenofibrate	Blood lipid regulator
Gemfibrozil	Blood lipid regulator
Propyphenazone	Anti-inflammatory drug
Sulfamethoxazole	Antibiotic drug
Ibuprofen	Anti-inflammatory drug
Naproxen	Anti-inflammatory drug
Diclofenac	Anti-inflammatory drug

The removal or transformation of HPV chemicals by biological treatment (activated sludge and membrane bioreactor [MBR]), disinfection (ultraviolet [UV] light, chloramines, chlorine), and advanced oxidation (ozone and ozone/hydrogen peroxide) processes was evaluated. The authors of the WERF report concluded the removal rate of Tier 1 and 2 compounds by MBR and activated-sludge treatments was largely similar at > 80%, indicating high efficacy by biological treatment. Of the conventional disinfection processes, chlorination represents a process for partial transformation of Tier 1 and 2 compounds and is an additional barrier for the removal of contaminants. Ozonation and ozone/hydrogen peroxide treatments can perform well to achieve higher effluent quality but do not eliminate 100% for all compounds (e.g., vanillin). Of the indicator compounds, some exhibited high rates of removal (e.g., ibuprofen, naproxen) and some compounds were not effectively removed (e.g., carbamazepine, primidone, diclofenac). The hydrophobic compounds are likely to be bound to solids and removed during the separation of sewage solids.

List of regulated organic contaminants

The *Guidelines for the Safe Application of Biosolids to Land in New Zealand* (2003) refer to (Paxeus 1996) who identified over 137 organic compounds in the influent of municipal wastewater plants but the authors stated that “a large number of substances present in the wastewater could not be positively identified due to a lack of their reference spectra”.

The only organic contaminants for which recommended limits have been set in the *Guidelines for the Safe Application of Biosolids to Land in New Zealand* (2003) include persistent organic pollutants (POPs), namely organochlorine pesticides, polychlorinated biphenyls and polychlorinated dibenzodioxins/furans (Table 2). The limits are based on the contaminant limits set by the New South Wales

Environmental Protection Agency (NSW EPA 1997) and the National Resource Management Ministerial Council of Australia (NRMMC 2003).

Since 1996, many more organic contaminants have been identified in biosolids around the world. In recent years, not only sewage effluent but also sewage-derived biosolids have been extensively characterised for organic contaminants. (Eriksson et al. 2008) and (Harrison et al. 2006) reviewed organic contaminants in sewage sludge in peer reviewed publications and government reports, and reported that 516 different EOCs had been determined in sewage sludge. Preliminary results from a New Zealand study looking at the efficacy of a range of sewage treatment technologies indicate that many EOCs including parabens, chloroxylenol and triclosan are poorly removed and still present in treated effluents (J Strong unpublished). EOCs determined in sewage sludge and their concentration ranges have been reported by (Harrison et al. 2006) under the following categories :

- Aliphatic hydrocarbons;
- Chlorobenzenes;
- Dioxins, furans and polychlorinated biphenyls;
- Endocrine disruptors, sterols and stanols;
- Flame retardants;
- Monocyclic hydrocarbons;
- Nitrosamines;
- Organic phosphate esters;
- Organotins;
- Pentachlorophenols (PCPs) and phenols;
- Pesticides;
- Pharmaceuticals and personal care products;
- Phthalates and plasticizers;
- Polycyclic aromatic hydrocarbons (PAHs);
- Polychlorinated biphenyls (PCBs),;
- Surfactants (nonylphenols and nonylphenoethoxylates).

An additional category of EOC were measured in sewage sludge by (Venkatesan & Halden 2013a). This was:

- Perfluoroalkyls (PFASs)

A US study measured 87 different organic chemicals representing a diverse cross section of EOCs that enter wastewater treatment plants in biosolids samples from across the country and demonstrated that biosolids contain higher levels of EOCs (as mass-normalized concentrations) than effluents (Kinney et al. 2006). The major EOC classes identified in biosolids were steroids and detergent metabolites followed by fragrances (Kinney et al. 2006). An survey of Australian biosolids measured similar concentrations of surfactants and triclosan (Langdon et al. 2011). Preliminary results from a New Zealand study measured a range of pharmaceuticals in biosolids (G Northcott unpublished). Some commonly used drugs, like acetaminophen, diclofenac and the beta-blocker metoprolol, were detected at relatively high levels.

In a Canadian biosolids land application study, the fate of 80 pharmaceuticals and personal care products (PPCPs) were monitored in groundwater, tile drainage, soil, and in the grain of wheat grown on the field for 1 year following application of biosolids (Gottschall et al. 2012). Concentrations of several PPCPs declined following exponential decay and none were detected in the grain of wheat (Gottschall et al. 2012). Another land application study on farmland in an arid area in the eastern plains of Colorado indicated that EOCs migrated downward through the soil by 468 days post-application but there was little uptake by mature wheat plants (Yager et al. 2014). The authors stated that more research is required to fully assess the risk of more persistent EOCs, particularly to predict potential effects of those that are persistent or can be mobilized. A recent NIWA study measured the concentrations of a range of EOCs in estuarine sediments from around Auckland found levels similar to those reported world-wide (Stewart et al. 2014). The main source is possibly sewage outfalls but the fact remains that EOCs are transported in the receiving environment and that vigilance is warranted to minimise other potential sources such as land application of biowastes.

Risk assessments

Despite gaps in knowledge, several risk assessments of a wide range of EOCs have been undertaken in order to evaluate the risk they may pose to human health and the environment. These risk assessment processes often require the estimation of exposure levels through likely exposure scenarios. In addition, these risk assessments often need to extrapolate toxic effects to humans and the environment from laboratory based experiments because of the paucity of knowledge about the effects of EOCs.

In addition, this lack of information on the fate and effects of EOCs means that subtle effects that may impact humans and ecosystems are not being considered and incorporated within existing risk assessment frameworks. The subtle effects may include blocking of multixenobiotic transporters leading to chemo-sensitisation and allergies (Schirmer et al. 2006), increased aggressive behaviour after selective serotonin reuptake inhibitors such as fluoxetine and sertraline accumulation (Daughton & Ternes 1999; Brooks et al. 2005) or abnormal behaviours due to exposure to endocrine disrupting compounds (Zala & Penn 2004).

Despite their shortcomings, comprehensive risk assessments are a useful tool to identify the potential risks that EOCs may pose on humans and the environment. For example Eriksson *et al.* identified 23 priority pollutants representing different chemical classes by a risk quantification process (Eriksson et al. 2008). These were:

- flame retardants and PCBs (DecaBDE, decabromobiphenyl and PCB 28);
- pesticides (endrin and triclosan);
- endocrine disruptors (17 β -estradiol, nonylphenol, nonylphenol mono-ethoxylate, pentachlorophenol);
- phthalates (DEHP and di-(i-nonyl) phthalate);
- PAHs (anthracene, benzo[*a*]anthracene, benzo[*b*]fluoranthene, benzo[*b*]fluorene, benzo[*ghi*]perylene, chrysene, fluoranthene and indeno [1,2,3-*cd*]pyrene);

- alkanes (phytane and pristane);
- cleaning agent linear alkylbenzene sulfonates (LAS).

Clarke and Smith extended this approach and ranked EOCs based on environmental persistence, human toxicity, evidence of bioaccumulation in humans and the environment, evidence of ecotoxicity and the number and quality of international studies focussed on the contaminant (Clarke & Smith 2011). They identified and ranked the following chemicals of concern in decreasing order of priority:

- perfluorinated chemicals (PFOS, PFOA);
- polychlorinated alkanes (PCAs);
- polychlorinated naphthalenes (PCNs);
- organotins (OTs);
- polybrominated diphenyl ethers (PBDEs);
- triclosan (TCS), triclocarban (TCC);
- benzothiazoles;
- antibiotics and pharmaceuticals;
- synthetic musks;
- bisphenol A (BPA);
- quaternary ammonium compounds (QACs);
- steroids;
- phthalate acid esters (PAEs);
- polydimethylsiloxanes (PDMSs).

International legislation

Despite awareness about EOCs in the environment (Daughton & Ternes 1999), international legislations controlling EOCs in sewage sludge are very diverse or non-existent. This may be partly due to the large number of potential contaminants, the relatively low levels of contaminants, and the gap in knowledge about the chronic effects of contaminants on human health and the environment. Overall, UK, USA and Canada claim that typical concentrations of organic micro pollutants in sewage sludge are not hazardous to soil quality, human health or the environment.

The EU policy on sewage sludge utilization (Mininni et al. 2014) proposed regulation of the following organic micropollutants:

- AOX;
- Sum of 7 PCBs (congeners 28, 52, 101, 118, 138, 153, 180);
- PCDD/F i.e. chlorinated dioxins and furans;
- Sum of 11 Polycyclic aromatic hydrocarbons (PAHs) acenaphthalene, benzo(a)pyrene, benzo(b)anthracene, benzo(ghi)perylene, benzo(j)anthracene, benzo(k)anthracene, fluoranthene, fluorene, indeno (1,2,3-cd)pyrene, phenanthrene and pyrene;
- Nonylphenols (NP) and nonylphenoethoxylates NPE;
- Phthalate (Di(2-ethylhexyl) phthalate – DEHP);
- Linear alkylbenzene sulfonates (LAS).

These organic micro pollutants in sewage sludge have been regulated in Austria, Czech Republic, Denmark, France, Germany and Sweden (Mininni et al. 2014). Regulation limits of organic micro pollutants vary between country and waste source, *i.e.* sewage sludge used in agriculture versus compost (Table 4).

The *Guidelines for the Safe Application of Biosolids to Land in New Zealand* (2003) currently limit selected organics including persistent chlorinated pesticides, PCBs and dioxins. When comparing the *Guidelines for the Safe Application of Biosolids to Land in New Zealand* (2003) with EU regulation, it becomes obvious that the NZ Guidelines are heavily slanted towards regulation of chlorinated persistent organic pollutants (CI-POPs). The focus on CI-POPs in the *Guidelines for the Safe Application of Biosolids to Land in New Zealand* (2003) reflected the goals of the NZ Government policy for the regulation and management of organic pollutants during the time they were produced. The CI-POPs were the subject of intense international research, prompted by their recognised persistence, bioaccumulation, and toxicity and were identified for elimination by the Stockholm Convention, of which NZ remains a signatory. Major reviews of organochlorine chemicals in the NZ environment undertaken by MfE identified relatively high concentrations of CI-POPs could be present in NZ sewage sludges. Hence the inclusion of these specific organic chemicals in the Biosolids Guidelines. In the years following the publication of the *Guidelines for the Safe Application of Biosolids to Land in New Zealand* (2003) New Zealand has implemented regulations either banning the importation, significantly restricting the use of, or eliminating activities that produce CI-POPs and release them into the environment. This has resulted in a significant reduction in the release of these chemicals into the NZ environment, and a visible decline in their concentrations within receiving environments in NZ.

The concentrations of most CI-POPs in NZ environment have continued to decrease and have either reached or are approaching what can be generally considered as “background” environmental concentrations. This continuing decrease in the quantity of CI-POPs released into the NZ environment is similarly reflected in their reduced concentrations in sewage sludges and biosolids. The US-EPA decided not to regulate dioxins in biosolids after studies demonstrated that this source does not pose a significant risk to human health or the environment (<http://www.epa.gov/ost/biosolids/dioxinfs.html>).

The requirement to monitor residues of CI-POPs in sewage sludges and biosolids in New Zealand places a considerable financial burden on biosolids producers to produce data that has limited questionable relevance.

In comparison there are many new organic chemicals of concern within sewage sludge and biosolids that have been identified as high risk or chemicals of concern internationally, and for which we have no or very limited data in New Zealand,

Table 4. Range of guideline limits of organic pollutants for sludge used in agriculture, compost and digestates (mg/kg DM) based on (Mininni et al. 2014) and compared with NZ biosolids guidelines (New Zealand Water Wastes Association 2003).

Class	Organic micro pollutant	Range of EU countries		NZ Sewage sludge and compost	
		Sewage sludge	Compost & Digestate	Grade a	Grade b
Perfluoro compounds	PFOS and PFOA		0.01		
Absorbable organic halogens	AOX	400 – 500	250 – 500		
Polychlorinated biphenyls	PCB sum	0.1 – 1	0.15 – 1	0.2	0.2
Dioxins	PCDD/F (ng/kg DM)	30 – 100	20 – 100	30	50
Polycyclic aromatic hydrocarbons	PAH sum	3 - 6	3 – 10		
Nonyl phenol and -ethoxylates	NP/NPE	10 – 450	10 – 25		
Phthalate	DEHP	50 – 100	50		
Linear alkyd benzene sulphonates	LAS	1300 – 5000	1300 – 1500		
Musks	Tonalide	15			
	Galaxolide	10			
Rubber tires	Mercaptobenzothiazole and hydroxybenzothiazole	0.6			
Pesticides	DDT/DDD/DDE			0.5	0.5
	Aldrin			0.02	0.2
	Dieldrin			0.02	0.2
	Chlordane			0.02	0.2
	Heptachlor and heptachlor epoxide			0.02	0.2
	Hexachlorocyclohexane			0.02	0.2
	Benzene hexachloride			0.02	0.2

The priority organic pollutants identified in the international literature for which regulatory limits need to be established are described in detail in Appendix A.

A list of potential priority organic micropollutants considered to be representative of the main classes of contaminants in sewage sludge (Table 5) has been proposed based on a hazard assessment approach (Eriksson et al. 2008).

Table 5. List of selected target compounds based on expert judgment some of which are included in EU regulations at levels shown in Table 4 (Eriksson et al. 2008).

Group	Selected compound
Aliphatic hydrocarbons	Hexadecane
Dioxins and furans	TCDD
Endocrine disruptors	4-Nonylphenol/nonylphenol Bisphenol A
Flame retardants	Tetrabromobisphenol A DecaDBE
PAH	Benzo[<i>ghi</i>]perylene Naphthalene Fluoranthene
Pesticide/antimicrobial	Triclosan
Pharmaceuticals	Ibuprofen
Phthalates and plasticisers	Di-(2-ethylhexyl) phthalate Di-(2-ethylhexyl) adipate
Surfactant	Linear alkylbenzene sulfonate (LAS)

Rationale for Selection and Incorporation of Organic Contaminants into Guidelines

It is challenging to select organic contaminants of concern for inclusion in the guidelines due to the large numbers of chemicals entering sewage systems and the knowledge gaps about their potential fate and effects. The first step is to assess the rationale behind the incorporation of the organic contaminants in Table 4.2 of the Guidelines. The MfE review of organochlorine residues in river and soil samples from across the country showed that environmental levels of PCDDs, PCDFs, PCBs, and organochlorine pesticides are low in New Zealand and markedly lower than concentrations reported in other developed countries (Buckland et al. 1998a; Buckland et al. 1998b).

Agrichemicals that have been identified as persistent organic pollutants (or POPs) wastes are deregistered and banned from use in New Zealand as per the Stockholm Convention on POPs of which New Zealand is a signatory. Safe, effective collection and disposal of these chemicals is required for New Zealand to meet its obligations under the Stockholm Convention (<http://chm.pops.int>). The 12 organochlorine chemicals initially listed as POPs under the Stockholm Convention in 2004 are aldrin, chlordane, DDT, dieldrin, endrin, heptachlor, mirex, hexachlorobenzene, toxaphene, PCBs, dioxins and furans. The elimination of these POPs in New Zealand is underpinned by managing their inputs to WWTPs via trade waste controls implemented by regional councils and territorial authorities. In general, the largest current day sources of POPs into the New Zealand environment are background atmospheric deposition and urban run-off. Therefore, it is unlikely that most of the organics listed in Table 4.2 of the Guidelines would accumulate within biosolids and their relevance is questionable. Most of the POPs listed in Table 4.2 have very few identifiable current day sources into biosolids in New Zealand, and those that exist can be effectively managed at the source. Currently the greater

proportion of POPs entering WWTPs in New Zealand occurs via diffuse background atmospheric deposition and depuration from the human population.

In comparison to POPs the use of products containing EOCs continues to grow in New Zealand with the result that increasing volumes enter WWTPs. There is a need to regulate EOCs because of the significant knowledge gaps regarding their fate and effects in the environment and the high perception of risk they pose, e.g. potential for EOCs in the soil to transfer to crops, contamination of drinking water.

The main reasons to regulate the concentration of organic contaminants in biosolids are if they:

- pose a risk to human and environment health, or the economy;
- accumulate in the environment through a lack of degradation or sufficiently high usage in relation to their degradation rate;
- pose a risk to groundwater.

The EOCs identified from the literature as priority organic micropollutants in sewage sludge (Table 5; Appendix A) provide insights into the type of chemicals to consider setting regulatory limits

Other Organic Wastes

In the *Guidelines for the Safe Application of Biosolids to Land in New Zealand* (2003), biosolids are defined 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”.

The term ‘biosolids’ and the *Guidelines for the Safe Application of Biosolids to Land in New Zealand* (2003) therefore do not apply to other solid biowastes such as untreated raw sewage sludges or sludges derived solely from industrial processes, animal manures, food processing and abattoir wastes.

Each organic waste type may contain specific types and concentrations of contaminants associated with particular practices. Nevertheless, the organic contaminants may have some similarity especially if blended products remain regulated under the Guidelines.

Organic waste comprised of animal manure has excellent fertilizer and soil conditioning qualities that are comparable to sewage sludge derived biosolids. However, overseas studies showed that many antibiotics enter the soil environment with the land application of poultry and pig manure. The concentration of veterinary medicines and antibiotics in animal manures are generally high because they are used as animal food supplements for growth promotion and therapeutic treatment. Pig manures in Austria, Germany and China have been demonstrated to contain a wide range of antibiotics (enrofloxacin, sulfamonomethoxine, oxytetracycline, tetracyclines, sulphonamides, chlortetracycline and sulfadimidine) with maximum concentrations ranging from 4 to 59 mg/kg (Heuer et al. 2011). The concentrations

of antibiotics in animal manure are often more than 10 times greater than that in sewage sludge.

In New Zealand, 47% of total antibiotics use (amounting to 75,000 kg) is associated with farmed animal production with approximately half consumed as growth promoters and prophylaxis (Sarmah *et al.* 2006). Nevertheless, only 6% of these antibiotics are used on ruminant animals and therefore it can be expected that sheep, beef, cattle and deer manure contains negligible amounts of antibiotics. In contrast, 19% of veterinary antibiotics are used on pigs and 74% on poultry (Sarmah *et al.*, 2006). Therefore pig manure and particularly poultry manure can be expected to contain antibiotic residues that may require monitoring and the setting of appropriate concentration limits.

Organic wastes comprised of compost containing greenwaste and in particular grass clippings can contain a range of pesticides used to control weeds and insects. These pyridine carboxylic acids, in particular aminopyralid, clopyralid and picloram are found consistently in compost from grass clippings that have been sprayed for broad leaf weeds. These compounds have a long active life and degradation, especially in biosolids can take up to 3 or 4 years. They remain active after animal and human excretion and after compost processing. Since the quality of compost will be included in any new Organic Waste Guideline and this group of herbicides is detected in compost pyridine carboxylic acids will need to be controlled in order to avoid damage to plants that the herbicide containing compost is applied to. The composting standards already refer to the contaminants from the Biosolids guidelines and there are already mechanisms in place to assess residual herbicidal activity including a plant bioassay and commercially available herbicide screen analysis.

Organic waste from viticulture, horticulture, crops, and vegetable processing may also contain some pesticides depending on the source but since they are applied to food crops regulation of pesticide application is likely to have been controlled during the food production cycle.

The forestry and the pulp and paper industries produce a range of organic wastes from sawdust and bark through to residual fibres and organic biomass from treatment ponds. Common contaminants in sawdust, depending on its source are the heavy metals copper chromium and arsenic which are regulated in the *Guidelines for the Safe Application of Biosolids to Land in New Zealand* (2003) and the New Zealand Timber Preservation Council Best Practice Guideline for the Safe Use of Timber Preservatives & Antisapstain Chemicals (2005).

Historically pulp and paper mills employed elemental chlorine to bleach pulp. This resulted in pulp mill effluent and sludges containing dioxins. However, since the late 1980s, elemental chlorine bleaching has been replaced by more environmentally friendly bleaching processes. These process changes have resulted in a significant reduction of effluent and sludge toxicity and impacts (van den Heuvel and Ellis 2002; Sandstrom and Neuman 2003). Pulp and paper mill sludges generally contain an abundance of resin acids and other extractives derived from wood lignin. Pulp mill solids exhibit low toxicity to oat, earthworm and enchytraeid worm test models, indicating that application of this material to land presents a low risk to terrestrial ecosystems (Fraser, 2007).

Other Considerations

The *Guidelines for the Safe Application of Biosolids to Land in New Zealand* (2003) are designed to safeguard the life-supporting capacity of soils, promote the responsible use of biosolids, protect public health and the environment and minimise risk to the New Zealand economy. The tools that are available for this are limiting exposure through:

- Controlling manufacturing and importation of products containing EOCs of concern;
- Improved wastewater and sewage sludge treatment;
- Imposing limits on annual loading rates of biosolids to land;
- Imposing limits on the specific contaminants of concern within biosolids.

This last option is used in the *Guidelines for the Safe Application of Biosolids to Land in New Zealand* (2003) and requires a well-defined and rational approach focusing on the more significant contaminants presenting a risk. The implications of requirements for costly analytical tests could hinder the beneficial recycling of organic wastes to land. Consequently, land application reuse option would continue to be too costly and alternative ways of disposal will continue to be favoured (e.g. landfill, incineration). It is therefore important to focus efforts and resources on selected indicator compounds that represent EOC classes associated with significant risk. By strategically choosing components to be included in the new Organics Waste Guideline, the on-going monitoring costs will not outweigh the benefits associated with land application options. There is on-going research investigating the fate and effects of EOCs and it would be beneficial to design a process within the Guidelines' framework allowing flexibility and responsiveness to incorporate and integrate outcomes from new scientific knowledge leading to reduced risk.

There is an increasing number of potentially harmful chemicals listed in the ingredients of domestic household products which has been identified as a point-source of EOCs in biosolids (Glegg & Richards 2007; Tremblay et al. 2013). It is a priority to engage with the wider community to assist them making better and more sustainable choices when purchasing household products. There are more initiatives to provide better information on the ingredients that are more likely to persist in the waste and represent human and environmental health risks (Goldsmith et al. 2014).

Conclusions and Recommendations

There is a strong perception of risk within the wider community when considering land application or reuse of organic wastes, especially biosolids. There are concerns about the range of contaminants that those wastes could contain and uncertainty about their potential health effects and adverse economic consequences related to environmental degradation. A study reported that there was significant risk with the application of biosolids to land as EOCs measured in

the biosolids bioaccumulated in earthworms (Kinney *et al.* 2012). However, it is not feasible to characterise and regulate all organic compounds when considering land application of organic wastes. Furthermore, even if all compounds were measured, there is still limited knowledge to suitably assess the risks of EOCs on the receiving ecosystems and human health (Tremblay *et al.* 2013).

The recommendations for organic contaminants to be monitored in a new Organic Waste Guideline are:

- The organic contaminants listed in Table 4.2 of the NZ guidelines can be considered as obsolete in view of the on-going research findings on the sources and fate of persistent organic pollutants in New Zealand;
- Alternatively, new and representative contaminants should be considered for inclusion in view of recent findings on the concentration and risk potential of EOCs in biosolids. Based on local and international literature, EOCs classes should include endocrine disruptors (e.g. nonylphenols and steroid hormones), flame retardants (e.g. HBCD and selected PDBEs), antimicrobial agents (e.g. triclosan and ciprofloxacin) and pharmaceuticals (e.g. carbamazepine, diclofenac); persistent herbicides (e.g. clopyralid); cleaning agent (LAS);
- At this stage, there is not enough information to derive New Zealand specific limits but interim values could be used as per Table 4;
- The derivation of New Zealand specific EOC limits should be based on actual risk. This process should be implemented by the development of a risk assessment framework;
- Other biowastes should be included in the revised guidelines and soil quality limits derived for the specific residue contaminants;
- The revised Guidelines should be based on a flexible and responsive framework to incorporate new and relevant scientific knowledge to facilitate the continued beneficial use of biowastes.

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Appendix A: Organic Micropollutants

Perfluoro chemicals (PFCs)

Perfluorinated chemicals are a family of synthetic chemicals that do not occur naturally. They have been used since the late 1950's to make products resistant to heat, oil, stains, grease and water. They are very resistant to degradation even

more than other halogen compounds that include bromine, chlorine (Clarke & Smith 2011). The perfluorinated chemicals can degrade to release in particular the environmentally persistent perfluorooctane sulphonate (PFOS) and perfluorooctanoic acid (PFOA). These monomers were identified as the top priority pollutant by (Clarke & Smith 2011) and PFOS concentrations were detected in all biosolids from 32 US states at levels averaging 403 ng/kg DM (Venkatesan & Halden 2013a). In addition, field investigation have demonstrated that PFCs in sludge amended soil can be mobilised by rainfall (Gottschall et al. 2010).

However, there are analytical difficulties associated with quantification of PFCs in sewage sludge (Clarke & Smith 2011). This may impact on the applicability of including PFOS and PFOA in any regulating guidelines. It may however be more practical and cheaper to measure a sum of halogens and regulate these. The sum of absorbable halogens AOXs have been regulated in various EU countries (Table 4).

Chlorinated dioxins and furans

Dioxins and furans are lipophilic compounds and will adsorb strongly to the soil phase. The compounds are very slowly degradable and thus bioaccumulate. The US EPA 2003 (<http://www.epa.gov/fedrgstr/EPA-TOX/2003/October/Day-24/t26923.pdf>) has decided not to regulate dioxin and dioxin-like compounds in sewage sludge. Nevertheless, chlorinated dioxin compounds were identified on the OSPAR (2002) list of substances of possible concern (Eriksson et al. 2008) and have been included in the regulations of various EU countries (Mininni et al. 2014). TCDD was chosen as a representative for this group because TCDD has the highest bioaccumulation factor and the highest measured soil sorption of the investigated dioxins (Eriksson et al. 2008). It is thus prone to accumulate in sludge amended soil.

In 2006, dioxin-like compounds were surveyed in Australian sewage sludge (Clarke et al. 2008). The average was found to be 5.6 ng TEQ/kg and were within the range of 1.2–15.3 ng TEQ/kg (n = 14). All the Australian sewage sludge samples were below the Victorian EPA “investigation limit” of 50 ng TEQ/kg, and well below the EU proposed guidelines (Table 1). Based on this study, (Clarke et al. 2008) concluded that the burden of dioxin-like compounds in Australian sewage sludge is low and its land application as biosolids is not likely to pose a problem (Clarke et al. 2008).

Analytical costs of chlorinated dioxins in New Zealand are extremely high compared to analytical costs of other compounds. (Clarke et al. 2008) found that there generally was a positive relationship between towns producing the waste and both dioxin-like PCDD/Fs and dioxin-like PCBs. This connection between PCBs and dioxins could utilise to save on analytical costs if it is decided that dioxins and PCB need to be regulated.

Polychlorinated biphenyls (PCB)

PCB is not included for assessment by (Eriksson et al. 2008)., as PCBs have been phased out in most countries, though some diffuse long-term leakage from existing buildings and installations may take place, it will not be in focus for substitution or improved source control

Polycyclic aromatic hydrocarbons (PAHs)

PAHs are included in the sludge related legislation in some EU countries, for example Denmark, and France. (Eriksson et al. 2008) suggest to choose 3 PAHs as measurable representative for high, medium, and low molecular weight PAHs as well as to cover a range of octanol–water partition coefficients and evaporation potential; (naphthalene, fluoranthene and benzo[ghi]perylene). These PAH compounds stem from urban runoff and air pollution due to combustion for heating and transportation purposes as well as other combustion and charring processes such as food preparation which results in a heavy load of PAHs in wastewater. Redirecting the stormwater away from municipal wastewater treatment plants will reduce the total load of PAHs found in sewage sludge (Eriksson et al. 2008).

Flame retardants

Polybrominated diphenyl ethers (PBDEs) are a class of fire retardants used in many products. There are 209 PBDE congeners. These compounds have low vapour pressures, and are highly lipophilic. They were listed as Persistent Organic Pollutants in the United Nations Environment Programme in 2008 (Clarke & Smith 2011). These PBDEs are routinely found in sewage sludge in the low mg/kg DM range and values have been reported in Sweden, Germany, Netherlands, China, Australia, Kuwait, Antarctica (Clarke and Smith, 2011) and US (Venkatesan & Halden 2014). Health risks associated with exposure to the most bioactive congeners (tri- to octa BDE) include thyroid hormone disruption, neuro-development defects and cancer (Clarke and Smith, 2011). The primary congener of decaBDE formulation (BDE209) is consistently detected in the highest concentrations in sewage sludge. Action in Europe has been taken to ban pentaBDE and octaBDE (Directive 2003/11/EC) and it is expected that their presence in sewage sludge will decrease (Clarke & Smith 2011). However decaBDE is a flame retardant compound that is still allowed to be used in the European Union (Eriksson et al. 2008). Therefore the high production volume compounds decaBDE and tetrabromobisphenol A were chosen by Eriksson et al. (2008) as compounds to represent flame retardants for monitoring or regulation purposes.

Surfactants (nonylphenols and nonylphenoethoxylates)

Alkylphenol ethoxylates (APEOs) are extensively used as surfactants in commercial and industrial products. Nonylphenol ethoxylates (NPEOs) represent about 80-85% of all APEOs, with an annual consumption estimated at 123,000 - 168,000 metric tonnes in the US. Due to their widespread use, significant amounts of APEOs enter sewage treatment plants, where they readily undergo biotransformation to alkylphenols (primarily nonylphenol) and their short chained ethoxylates (mono- and diethoxylates). Nonylphenol was the most abundant analyte (534 ± 192 mg/kg) in a biosolids survey across 32 US states (Venkatesan & Halden 2013b), followed by its mono- and di-ethoxylates (62.1 ± 28 and 59.5 ± 52 mg/kg, respectively). Nonylphenol compounds showed observable loss from sewage sludge/soil mixtures (1:2), with mean half-lives ranging from 301 to 495 days (Venkatesan & Halden 2013b). (Eriksson et al. 2008), identified 4-nonylphenol as a potential risk in a recent hazard assessment. Nonyl phenol and –ethoxylates are regulated under European regulations (Mininni et al. 2014).

Surfactant levels in US sewage sludge were 10 times in excess of European regulations and (Venkatesan & Halden 2013b) argued that these levels in excess of EU regulations, substantial releases to U.S. soils, and prolonged half-lives found under field conditions would be a good reason to regulate these chemicals in the US.

Pharmaceuticals and antibiotics

Pharmaceuticals are bioactive compounds by their very nature. They are often not fully metabolised and enter the environment via sewage effluent and sewage sludge. There are many different pharmaceuticals and their fate depends on the individual characteristics of each compound, their partitioning coefficients and biodegradability. (Eriksen et al. 2009) evaluated 1400 pharmaceutical compounds based upon a tiered approach where chemicals were screened against consumption, volume wastewater of influent, human metabolism, biodegradation and behaviour in sewage treatment plants. They identified 14 pharmaceuticals for further risk assessment. These were: atorvastatin (cholesterol lowering medication); carisoprodol, gabapentin (analgesic/pain killer); mesalazine (anti-inflammatory); chlorprothixene (anti-psychotic); ciprofloxacin, tetracycline (antibiotic); ranitidine (inhibits stomach acid production); levetiracetam (anticonvulsant/epilepsy); and dipyridamole, losartan, fexofenadine, metoprolol (blood and heart treatments).

The most abundant pharmaceutical and personal care products detected in sewage sludge across 32 US states were the disinfectants triclocarban and triclosan, with mean concentrations ranging from 12 to 36 mg/kg. The second most abundant class were antibiotics. In order of decreasing concentration these were ciprofloxacin, 4-epitetracycline, tetracycline, minocycline, doxycycline, azithromycin, miconazole and norfloxacin (McClellan & Halden 2010) with corresponding mean contents ranging from 0.3 mg/kg to 7 mg/kg. In a Swiss study, norfloxacin and ciprofloxacin were also detected in sewage sludge and in soil 21 months after land application of sewage sludge (Golet et al. 2002; Golet et al. 2003). The most abundant non-antibiotic pharmaceuticals in decreasing order were cimetidine, caffeine, carbamazepine, gemfibrozil and naproxen. The mean contents of these compounds ranged from 0.2 to 0.5 mg/kg (McClellan & Halden 2010). Especially carbamazepine, is very persistent during sewage treatment and in soils, and is only retained by soils high in organic matter (Gielen et al. 2009) and it was found to be translocated into the aerial components of plants (Dolliver et al. 2007; Winker et al. 2010).

Several pharmaceuticals found in sewage sludge are antibiotics and the main concern with antibiotics is their ability to cause antibiotic resistance in the receiving environment. Many antibiotics, however, enter the soil environment with the land application of animal manure. Antibiotic levels in animal manure are generally high because antibiotics are used as animal food supplement for growth promotion in addition to therapeutic treatments. In Austria, Germany and China pig manure was analysed for a range of antibiotics (enrofloxacin, sulfamonomethoxine, oxytetracycline, tetracyclines, sulphonamides, chlortetracycline and sulfadimidine) and maximum levels ranged from 4 to 59 mg/kg (Heuer et al. 2011). The abundance of antibiotics in manure is often more than 10 times larger than antibiotics levels found in sewage sludge.

Applying manure increased the numbers of resistant genes but there was already a considerable pool of resistance genes in soils (Heuer et al. 2011). The usage of antibiotics in animal husbandry has promoted the development and abundance of antibiotic resistance in farm environments. Manure has become a reservoir of resistant bacteria and antibiotic compounds, and its application to agricultural soils is assumed to significantly increase antibiotic resistance genes and selection of resistant bacterial populations in soil. The human exposure to soil-borne resistance has yet to be determined, but is likely to be severely underestimated (Heuer et al. 2011).

(Eriksen et al. 2009) suggested that pharmaceutical substances in sewage sludge are sufficiently lower than predicted effects concentrations and therefore constitute a low risk to the soil compartment. In addition, it is impossible to regulate all bioactive compounds. Nevertheless, the selection of a few key components would give a good indication on a general abundance. Therefore it is proposed to choose 3 indicators; triclosan(or tricloban) because they are the most abundant bioactive compound; ciprofloxacin because it was one of the most abundant antibiotic; and carbamazepine because it has a real potential to contaminate groundwater (Gielen et al. 2009).

Phthalates and plasticizers

Phthalate acid esters have been used for over 50 years mainly in the manufacturing of resins and plastics (PVC), paints, rubber, adhesives and some cosmetics. Phthalate acid esters such as di-(2-ethylhexyl) phthalate (DEHP), soften plastics without chemically binding and the PAEs content generally ranges from 20% to 40% and in some cases 55% (Clarke, et al., 2011). These phthalates easily leach from plastics and in a sewage treatment plant partition strongly to sewage sludge. The levels of DEHP, the most common phthalate, in sewage sludge ranges from the low mg/kg to 200 mg/kg (Clarke, et al., 2011). Phthalates are classified as endocrine disruptors. However, phthalates are not environmentally persistent and can be degraded in sewage sludge and soil both aerobically and anaerobically (Clarke, et al., 2011). Nevertheless, phthalates can be taken up in plants but phthalates are readily metabolised in mammals. Mammals ingesting high doses of phthalates were able to quickly remove them from body tissues once the chemical was excluded from the feed (Clarke, et al., 2011). This would indicate that the risks from continuous supply rather than from accumulation would need to be considered.

Endocrine disruptors, sterols and stanols

Bisphenol A is widely found in households and industry among others in the coating of metal cans to prevent the metal contact with food. It is found in raw sewage and surface waters primarily because it is continuously released into the environment and not because it is environmentally persistent. Bisphenol A is found in sewage sludge at levels ranging from low µg/kg to mid mg/kg levels. It has been included as a compound of possible concern because of its endocrine disrupting abilities (Clarke & Smith 2011) and is included in the OSPAR List of substances of possible concern. Bisphenol A is an endocrine disruptor that can be found in the human body (Lee et al. 2008), but exposure primarily occurs in the domestic environment and via direct ingestion. Transfer to humans from biosolids-amended

soil is unlikely since there is little evidence that bisphenol A is environmentally persistent or bioaccumulates via the food-chain (Clarke & Smith 2011).

Natural hormones from animals are spread with manure. It was found that these natural hormones contribute much more than sewage sludge to the total land application of hormones in Denmark (Eriksen et al. 2009). Therefore natural hormones are unlikely in need of regulation.

Organotins

Organotin compounds have been used since the 1960s for industrial and agricultural purposes such as polyvinyl chloride (PVC) stabilisers, fungicides, bactericides, insecticides, industrial catalysts and wood preservatives. During sewage treatment, these organotin compounds are effectively concentrated in the sewage sludge fraction. Organotin compounds have been reported in sewage sludge in Switzerland, France, Canada, and the UK (Clarke & Smith 2011). Levels are generally below 1 mg/kg and are predicted to decline with the internationally decrease in the use of compounds like tributyltin (Clarke & Smith 2011).

Pentachlorophenols (PCPs)

PCP is abandoned in many countries and therefore not considered relevant in spite of its high score in environmental risk assessments (Eriksen et al. 2009).

Pesticides

The contribution to land via sewage sludge application is in comparison to the direct application considered of minor importance. These compounds and their risks are often controlled by banning the import and sales. In the EU, this is the case for Endrin, which was identified as a high environmental risk, and was banned in the EU. In time, this will decrease exposure (Eriksen et al. 2009).

Despite that the use of pesticides is mostly controlled, there is a group of herbicides found consistently in compost from grass clippings that have been sprayed for broad leaf weeds. These compounds have a long active life and degradation, especially in biosolids can take up to 3 or 4 years. The group of herbicides are pyridine carboxylic acids, in particular aminopyralid, clopyralid and picloram are persistent. They remain active after animals and humans excretion and after compost processing. Since the quality of compost is included in the NZ Biosolids Guidelines, and this group of herbicides is detected in compost pyridine carboxylic acids will need to be controlled in order to avoid damage to plants that the herbicide containing compost is applied to.



7th August 2017

Nick Walmsley,
WaterNZ
Ranchhod House,
Level 12,
39 The Terrace
PO Box 1316

Dear Nick,

Review and recommendations on the selection of organic contaminants in the draft Guideline for the Beneficial Use of Organic Waste Products on Land, 2016.

As requested by Water New Zealand find enclosed a report from Northcott Research Consultant's Limited (NRC Ltd) entitled "A reassessment of organic contaminants and their product contaminant concentration limits within the draft Guideline for the Beneficial use of Organic Waste Products on Land".

As directed by the Project Steering Group overseeing the preparation of the draft Guideline this report provides:

- a justification for changing the organic contaminants in the original draft guideline
- a short list of EOCs for monitoring in the new guideline
- Recommended product limits for the short list of EOCs
- Recommended methodology for analysis of the afore mentioned EOCs

Kind regards.

Dr Grant Northcott PhD

A handwritten signature in black ink, appearing to read "G. L. Northcott", is enclosed in a light grey rectangular box.

Director: Northcott Research Consultants Limited
Environmental Chemist: Centre for Integrated Biowaste Research



**A REASSESSMENT OF ORGANIC CONTAMINANTS AND THEIR PRODUCT
CONTAMINANT CONCENTRATION LIMITS WITHIN THE DRAFT GUIDELINE FOR
THE BENEFICIAL USE OF ORGANIC WASTE PRODUCTS ON LAND**

Prepared for Water New Zealand by Dr Grant Northcott

Northcott Research Consultants Limited (NRC Ltd)

August 2017.

EXECUTIVE SUMMARY

Northcott Research Consultants Limited (NRC Ltd) was contracted by Water New Zealand to review and justify the selection of organic contaminants and their respective product contaminant concentration limits specified in the draft Guideline for the Beneficial Use of Organic Waste Products on Land, 2016. (Water New Zealand, 2016).

Specifically, NRC Ltd was directed by the Project Steering Group overseeing the preparation of the draft Guideline to provide:

- a justification for changing the organic contaminants in the original draft guideline
- a short list of EOCs for monitoring in the new guideline
- Recommended product limits for the short list of EOCs
- Recommended methodology for analysis of the afore mentioned EOCs

An assessment of the latest information of their concentration in biowaste, the risk they present to the environment upon biowaste application to land, and regulations for their elimination or restricted use, was completed for those organic contaminants proposed for product concentration limits in the draft Guideline for the Beneficial Use of Organic Waste Products on Land.

Recommendations from this assessment include:

- removing PFOS\PFOA, AOC and polycyclic aromatic hydrocarbons from the list of contaminants requiring product concentration limits in the draft Guideline for the Beneficial Use of Organic By-Products on Land.
- Increasing the product concentration limits for NP\NPE, DEHP, LAS and galaxolide in the draft Guideline for the Beneficial Use of Organic By-Products on Land.

The recommended organic contaminants and respective product contaminant concentration limits proposed for inclusion in the Guideline for the Beneficial Use of Organic By-Products on Land are displayed in the table below.

Contaminant	Parameter	Concentration limit (mg/kg dry weight)
Arsenic		30
Cadmium		10
Chromium		1500
Copper		1250
Lead		300
Mercury		7.5
Nickel		135
Zinc		1500
Nonylphenol and ethoxylates ^A	NP/NPE	50
Phthalate	DEHP	100
Linear alkylbenzene sulphonates ^B	LAS	2600
Musks	Tonalide	15
	Galaxolide	50

^A comprising the sum of technical nonylphenol, NPE10 and NPE20 equivalents

^B comprising the sum of technical C11-C13 homologues and corresponding mixture of isomers

Due to the low risk that NP\NPE, DEHP, LAS and galaxolide present to the environment or human health from the application of biowaste to land, the product contaminant concentration limits for NP\NPE, DEHP, and LAS have been raised to equal those proposed by the European Union in sludge applied to agricultural soil, and to 50 mg/kg for galaxolide.

Guidance on recommended methodological approaches for analysing the recommended organic contaminants in biowaste that reduce the complexity and labour of analysis, and therefore reduce the cost of analysis are provided. This includes general advice on:

- approaches to minimise the number of separate sample extractions required to extract the modified list of organic contaminants from biowaste
- instrumental analysis approaches that reduce the number of separate runs required to analyse the diverse list of organic contaminants in biowaste, and,
- specific recommendations regarding the analysis of residues of industrial mixtures of NP/NPEs and LAS inorganic biowaste, and how to report residues of these industrial mixtures.

INTRODUCTION

The focus on Cl-POPs in the Guidelines for the Safe Application of Biosolids to Land in New Zealand (2003), referred to hereafter as the 2003 Biosolids Guidelines, reflected the goals of NZ Government policy for the regulation and management of organic pollutants at the time the Guidelines were produced.

In the years preceding and following the publication of the 2003 Biosolids Guidelines the NZ Government implemented regulations either banning the importation, significantly restricting the use of, or eliminating activities that produce Cl-POPs and polychlorinated dibenzodioxins and Furans (PCDD/Fs) and released them into the environment. These combined controls have resulted in a significant reduction in the release of these chemicals into the NZ environment, and a visible decline in their concentrations within receiving environments in NZ. The concentrations of most Cl-POPs in the NZ environment have continued to decrease and have either reached or are approaching what can be generally considered as “background” environmental concentrations.

This continuing decrease in the quantity of Cl-POPs released into the NZ environment is similarly reflected in their reduction in sewage sludge’s and biosolids.

Phase Two of the 2004 Cross-Departmental Research Programme “Removing the Roadblocks to the Beneficial Use of Sewage Effluent and Biosolids” analysed a wide range of organic contaminants in sewage sludge obtained from ten wastewater treatment plants in New Zealand on three separate occasions. Not one of the thirty analysed sewage sludge’s contained any detectable residues of a suite of Cl-POPs, including those specifically listed for control in the 2003 Biosolids Guidelines. Due to the expense of analysis PCDD/Fs were not analysed within the 2004 CDRP project. However, the US-EPA decided not to regulate dioxins (PCDD/Fs) in biosolids after research demonstrated this source does not pose a significant risk to human health or the environment (USEPA).

The requirement to monitor residues of Cl-POPs and PCDD/Fs in sewage sludges and biosolids in New Zealand was appropriate at the time the 2003 Biosolids Guideline was under development. However, it has since been demonstrated it is no longer necessary to monitor these persistent chlorinated organic pollutants in sewage sludge and biosolids in New Zealand.

In comparison, many new organic chemicals, commonly referred to as emerging organic contaminants (EOCs) that are present in sewage sludge and biosolids, have been identified internationally as high risk or chemicals of concern. In response the Centre for Integrated Biosolids Research (CIBR) completed a review assessing the relevance of the organic contaminants listed in the 2003 Biosolids Guidelines together with high risk EOCs either proposed for regulation or monitoring in overseas countries.

As stated in the 2014 CIBR review, the selection of organic contaminants to include within a revised Organic Materials Guideline new guideline “should be based on a flexible and responsive framework that incorporates new and relevant scientific knowledge”. As such it is expected that new high risk organic contaminants will be assessed and considered for incorporation into the modified Guidelines, and others removed, as our knowledge of the effects and risks of traditional and emerging chemicals increases.

As stated in the 2014 CIBR review of organic contaminants there is not enough information currently available to derive New Zealand specific limits for emerging organic contaminants in biowastes. Instead, the 2014 CIBR review of organic contaminants suggested applying interim values that could be adopted for limiting the concentration of selected EOCs in biowaste as listed in Table 1 (Tremblay et al, 2014). The European guideline limits for organic contaminants were sourced from the review of European

policy on sewage sludge utilisation by Mininni which summarised the limits of selected organic micropollutants in sewage sludge, compost, and digestate adopted by the European Union, and its member countries (Mininni et al, 2015).

The EU definition for compost is the residue remaining after the aerobic decomposition of biomass and digestate is defined as the residue remaining after anaerobic digestion of biomass, typically by fermentation processes. In the EU digestate is most often produced in the operation of biogas plants and consists of the liquid fermentation residue remaining after the separation recovery of fermentation biogases. These digestates are highly valued as fertilisers. In the EU energy crops and liquid manures are predominantly used as feedstock for the production of biogas but in principal all organic materials are suitable feedstock. Under these descriptions the residue produced from municipal sewage sludge subjected to anaerobic digestion could be considered a digestate.

Table 1. Range of guideline limits of organic pollutants for sludge used in agriculture, compost and digestates (mg/kg DM) based on Mininni (Mininni et al. 2014) and compared with NZ biosolids guidelines (New Zealand Water and Wastes Association 2003).

Class	Organic Micropollutant	Limits for EU Countries		Limits for NZ	
		Sewage Sludge	Compost and digestate	Grade A	Grade B
Perfluorinated compounds	PFOS/PFOA	NA	0.01	NA	NA
Absorbable organic halides	AOX	400-500	250-500	NA	NA
Polychlorinated biphenyls	Sum of various congeners	0.10-1.0	0.15- 1.0	0.20	0.20
Chlorinated dioxins and furans	PCDD/Fs	30-100 ^B	20-100 ^A	30 ^A	50 ^A
Polycyclic aromatic hydrocarbons	Sum of various compounds	3.0-6.0	3.0- 10.0	NA	NA
Total nonylphenols	Sum of NP and NPE ^C	10-450	10-25	NA	NA
Phthalate	DEHP	50-100	50	NA	NA
Linear alkylbenzene sulphonates	LAS ^D	1300-5000	1300-1500	NA	NA
Musks	Tonalide	15	NA	NA	NA
	Galaolide	10	NA	NA	NA
Bubber vulcaniser and stabilisers	Mercaptobenzothiazole				
	Hydroxybenzothaizole	0.60	NA	NA	NA

^A Not available, no limit; ^B ng of toxic equivalents (TEQ)/kg dry matter; ^C sum of nonylphenol and nonylphenol ethoxylates, varies between member countries; ^D does not specify which chain length classes are included

The list of proposed organic contaminants and suggested interim limits was subsequently incorporated into the draft Guideline for the Beneficial Use of Organic Waste Products on Land (NZ Water, 2016), hereafter referred to as the draft Guideline. The product contaminant concentration limits contained within Table 5.5 of the draft Guideline are reproduced below in Table 2.

The proposed product contaminants and their concentration limits were widely discussed during and after a series of National Workshops run by Water New Zealand to publicise and seek input into the draft Guideline for the Beneficial Use of Organic Waste Products on Land.

In the three years following the preparation of the 2014 CIBR report significant advancements have been made in both research and the state of knowledge of EOCs, particularly with respect to their presence in biosolids and other waste materials. Regulatory organisations worldwide have begun responding to the challenges of managing the potential risks EOCs may present to the environment and human health.

Table 2. Product contaminant concentration limits as specified in the draft Guideline for the Beneficial Use of Organic Waste Products on Land, 2016. (Water New Zealand, 2016).

Contaminant	Parameter	Concentration limit (mg/kg dry weight)
Arsenic		30
Cadmium		10
Chromium		1500
Copper		1250
Lead		300
Mercury		7.5
Nickel		135
Zinc		1500
Perfluoro- compounds	PFOA/PFOS	0.01
Adsorbable organic halide	AOX	450
Polycyclic Aromatic Hydrocarbons	Sum of PAHs	5.0
Nonylphenol and ethoxylates	NP/NPE	25
Phthalate	DEHP	75
Linear alkylbenzene sulphonates	LAS	1500
Musks	Tonalide	15
	Galaxolide	10

Source: Water New Zealand, 2016.

In light of these developments it is pertinent to reconsider which organic contaminants to retain, remove, or modify concentration limits for, within the draft Guideline.

The following sections of the report discuss the rationale for reducing the number of organic compounds and testing parameters, and where appropriate modifying the Product contaminant concentration limits, specified within the draft Guideline (Table 2).

General recommendations on methodological approaches that analytical laboratories can adopt to reduce the cost to analyse a modified list of organic contaminants are also provided.

PRODUCT ORGANIC CONTAMINANT LIMITS

The organic contaminants specified for limitation in products within the draft Guideline for the Beneficial Use of Organic Waste Products on Land are discussed in the order they appear in Table 5.5 of the draft Guideline (Table 2 in this report).

Polyfluorinated chemicals- PFOS and PFOA

The environmental persistence and bioaccumulation potential of long chain perfluorotelomers, their degradation products, and perfluoroalkyl acids has seen worldwide enforcement of restrictions and regulations for these chemicals. The extreme level of persistence and high bioaccumulation potential of these perfluorinated chemicals is exemplified by polyfluorooctanoic acid (PFOA) and polyfluorooctane sulphonate (PFOS) which are considered ubiquitous, stable, and toxic environmental contaminants. The profile of perfluorinated chemicals in biosolids and the environment is dominated by PFOA and PFOS.

A summary of concentration of PFOS/PFOA measured in sewage sludge and biosolids in the USA, Australia and Germany is provided below in Table 3.

Table 3. Concentration of PFOS and PFOA in sewage sludge and biosolids

Country	Year	Concentration in mg/kg dry weight		Reference
		PFOS	PFOA	
USA	2001	0.308 - 0.618	0.012 - 0.070	Venkatesan, 2013
Australia	2014	0.011 - 0.370	0.003 - 0.030	Gallen, 2016
Germany	2008- 2013	0.012 - 0.050 (7.6) ^A	0.0003 - 0.016 (1.04) ^A	Ulrich, 2016
Various	Various	0.005- 3.12	0.001-0.244	Clarke, 2001

^A Range of mean concentrations with maximum concentration in brackets

The European Union has not set a concentration limit for perfluorinated chemicals in sewage sludge, compost, or digestate. However, member countries Austria and Germany apply a limit of 0.01 mg/kg for the sum of PFOA/PFOS in compost or digestates (Mininni et al, 2015).

In 2008 the Bavarian State Ministry for the Environment in Germany implemented a policy enforcing the analysis of PFAAs in WWTP sewage sludge and set a precautionary limit of 0.125 mg/kg dry matter for the sum of 11 PFAAs in sewage sludge applied to land or used for the production of compost (Ulrich et al, 2016).

As previously stated PFOS/PFOS contribute the greater proportion of total PFAAs residues in biosolids and the environment. The concentration limit for polyfluorinated organic chemicals in the draft Guideline was set at 0.01 mg/kg for the sum of PFOA/PFOS. Comparison of this limit with the concentration of PFOS and PFOA commonly present in sewage sludge's and biosolids (listed in Table 3) clearly demonstrates this limit would be difficult for most countries to comply with. In comparison a large proportion of the sludge's and biosolids would meet the Bavarian State Ministry for the

Environment precautionary limit of 0.125 mg/kg dry matter for the sum of 11 PFAAs in sewage sludge applied to land or used for the production of compost.

It is important to note the source of the Product Contaminant Concentration Limit of 0.01 mg/kg DM for the sum of PFOS + PFOA was adopted from that set in Austria and Germany for PFOS + PFOA in compost and digestate, and not biosolids. The processing of biosolids to produce compost products, and/or anaerobic digestion of biosolids containing PFOS/PFOA, will reduce the concentration of PFOS/PFOA they contained before they were subject to these processes.

Concerns regarding the persistence and bioaccumulative properties of long chain PFAAs have resulted in worldwide regulations and restrictions on these chemicals. In 2008 the EU prohibited the general use of PFOS and its derivatives, restricted its content in semi-finished and finished products to 50 mg/kg, and provided exemptions for the semiconductor industry, metal plating, and hydraulic fluids. In 2010 the acceptable content was reduced further to 10 mg/kg (EU, 2010) and since 2011 the EU has banned the use of firefighting foams based on PFOS.

In 2009 PFOS and its salts were added to the assessment list of POPs of the United Nations Stockholm Convention and in 2017 were officially classified as new POPs under the Stockholm Convention (UNEP, 2017). In anticipation of this move eight of the major fluoropolymer and telomere manufacturing companies initiated a voluntary phase-out program for PFOA, its pre-cursors, and higher homologues in 2006 with the goal to totally eliminate their use of these chemicals by 2015.

Over the next two years the combined impact of these initiatives and regulations will see a significant reduction in the use of these perfluorinated chemicals, and corresponding reduction in the concentration of PFOS/PFOA in sewage sludge's, biosolids, and products produced from them..

The reduction in the use of PFOA and other higher perfluorinated homologues has been matched by their substitution with alternative shorter chain PFAAs that have the advantage of being less bioaccumulative. However, these shorter chain substitutes remain persistent, display a high level of mobility in the environment, and are more difficult to remove from wastewater because as a result of their reduced adsorption affinity to sewage sludge (Ulrich et al, 2016). Effort should therefore be focused on assessing the environmental and human health risks of shorter chain PFAAs and other perfluorinated chemicals that have been adopted as substitutes for PFOS/PFOA.

In conclusion there is little reason to include a product contaminant concentration limit for PFOS/PFOA in organic wastes within the draft Guideline when these chemicals are being phased out of use and have been officially added to the list of POPs for elimination under the Stockholm Convention.

In 2017 CIBR is initiating a research project to identify and assess the potential risks presented by perfluorinated chemicals in biosolids and biowaste applied to land in New Zealand. The outcomes and recommendations arising from this research will be published and the research papers provided to Water NZ and other end-users for considering whether product contaminant concentration limits need to be considered for perfluorinated chemicals other than PFOS/PFOA within the Guideline for the Beneficial Use of Organic Waste Products on Land.

Adsorbable Organic Halide (AOX)

AOX remains on the list of European list of contaminants in sewage in response to the presence of chemical manufacturing industries within member states and the production of industrial sludge's

containing very high concentrations of halogenated organic chemicals. The AOX test method provides an economic alternative to analysing the multitude of halogenated organic chemicals produced by the chemical industry, and as such has been widely adopted by these industries as a proxy measure.

The reliability of the AOX test method for the analysis of biosolids is a matter of ongoing debate and there is a lot of concern about the reliability of AOX measurements in sewage sludge and biosolids. The suitability of the AOX method depends on halogenated organic chemicals being efficiently extracted from sewage sludge/biosolids by a nitric acid solution, and then being efficiently adsorbed by the activated organic carbon. A large proportion of the halogenated organic chemicals identified in sewage sludge/biosolids are hydrophobic and will not readily partition into the nitric acid extracting solution. Furthermore, the high residual content of humic substances in sewage sludges/biosolids can compete for adsorption sites on the activated carbon, thereby reducing the adsorption of halogenated organic chemicals that are extracted from sewage sludge/biosolids.

The AOX method is intended to extract a wide range of chlorinated organic chemicals from sewage sludge as diverse as chlorinated alkanes, chlorinated benzenes, chlorinated phenols, PCBs and PCDD/Fs. This makes it an almost meaningless parameter to utilise to assess the toxicological risk of chlorinated organic compounds in biosolids and biowaste applied to land because:

1. The heterogeneous nature of biosolids and biowaste means measures of AOX will vary significantly between different WWTPs and processing methods.
2. The compounds included within the AOX analysis display a wide range of very different physico-chemical properties. As such their persistence and fate in soil amended with biowaste will vary widely.
3. Similarly, the compounds encompassed by AOX display widely different modes of toxicity, and toxic potency. For example, chlorinated benzenes are found in biosolids at relatively high concentrations and therefore can make a large contribution to total AOX. However, chlorobenzenes display a relatively low degree of persistence and toxicity in soil amended with biosolids and a correspondingly small contribution to the overall risk of applying biowaste to land.

A requirement to monitor AOX in biowaste within the modified Guideline would not provide any useful information to assist waste practitioners or regulators to reach any meaningful conclusions about the risk of applying biowaste to land. In summary there is little scientific rationale to retain AOX as a product contaminant parameter to monitor in organic waste products within the modified Guideline.

Polycyclic Aromatic Hydrocarbons (PAHs)

PAHs are often listed as priority contaminants in biosolids in countries where urban storm water is reticulated and directed into WWTPs for treatment, in which case biosolids accumulate high concentrations of combustion and fuel sourced PAHs (for example in the UK). In New Zealand urban storm water drainage networks are typically kept separate from municipal waste water streams, and the concentration of PAHs entering WWTPs in NZ is relatively low. This has been confirmed by recent and unpublished New Zealand data.

PAHs degrade relatively rapidly in microbially active material and as such many of the stabilisation processes to which organic waste materials (composting, vermicomposting etc.) are subjected should be sufficient to degrade PAHs. Any residues of PAHs remaining in stabilised biowastes added to land will be

degraded further by soil microbes and their bioavailability for uptake into crops and pasture reduced by sorption to the soil matrix and the formation of bound residues.

Research in the United Kingdom has demonstrated the annual mass loading of PAHs into soil resulting from the application of sewage sludge to land at recommended agronomic rates, is significantly less than that attributed to atmospheric deposition of combustion derived PAHs to soil (Duarte-Davidson et al, 1995).

Combustion derived waste material is not a raw organic material and wastes such as these are not listed as suitable organic materials in the modified Guideline. Biochar produced by the reductive combustion of organic wastes (plant material, animal waste etc.) can contain considerable quantities of PAHs. The stability of biochar is such that it is non-compostable and as such the draft Guideline excludes its use as an organic waste material.

In conclusion organic waste materials meeting the definition in the new Guideline should contain relatively low concentrations of PAHs that present little or no risk to the environment or human health, and PAHs can therefore be removed as a product contaminant within the draft Guideline.

Nonylphenols

Alkylphenol ethoxylates are a class of non-ionic surfactants, produced by the reaction of a branched-chain alkylphenols with ethylene oxide. The most commonly used are nonylphenol ethoxylates (NPEs), which make up approximately 80% of the world market. Commercial formulations, commonly referred to as technical nonylphenol ethoxylates, are composed of a complex mixture of homologues, oligomers and isomers containing anywhere between 1 to 50 ethoxy chain lengths.

The use of NPEs in domestic detergents has largely ceased and they are mainly used as industrial surfactants. The starting material for the manufacture of technical NPEs is technical nonylphenol, which is comprised of the same complex mixture of homologues, oligomers and isomers as the technical NPE product.

Technical NPE products are degraded by microorganisms which progressively break down the ethoxy chains to produce as metabolites the original technical NP mixture together with corresponding mixtures of nonylphenol monoethoxylates (NP1EOs) and nonylphenol diethoxylates (NP2EOs). During wastewater treatment processes technical NPEs are rapidly degraded to produce the corresponding mixture of technical NPs, NP1EOs, and NP2EOs. The mixtures of NP1EOs, and NP2EOs are degraded further during anaerobic digestion to produce the corresponding mixture of technical NPs. The composition of technical nonylphenolic compounds in anaerobic digested sludge is typically 95% technical NP and 5% technical NP1EOs and NP2EOs (Ahel et al, 1994).

The principle concern regarding the toxicological risk of nonylphenols is their estrogenicity. The nonylphenol compound exhibiting the highest estrogenic potency is 4-n-nonylphenol. However, 4-n-nonylphenol is only one of many individual nonylphenol compounds present in industrial mixtures of technical-NP, or those produced by the degradation of parent technical mixtures of NPEs. The concentration of 4-n-NP measured in New Zealand biosolids in the 2004 CDRP project ranged from 0.005 to 0.240 mg/kg dry weight biosolids. In comparison the concentration of technical-NPs was orders of magnitude higher and varied from 10.3 to 1843 mg/kg dry weight biosolids.

NPs and NPEs are rapidly biodegraded in biosolid amended soil. A risk assessment of contaminants in sewage sludge applied on Norwegian soils concluded the sum of NP/NP1EOs/NP2EOs at a concentration of 100mg/kg DM in sewage sludge constituted a low risk to the soil ecosystem and didn't constitute a significant risk to aquatic or food producing environments (Norwegian Scientific Committee for Food Safety,2009).

The Product contaminant concentration limit of 25mg/kg NP/NPE specified in the draft Guideline for the Beneficial Use of Organic Waste Products on Land was adopted from the recommendations in the 2014 CIBR review (Tremblay et al, 2014). This concentration limit represents the concentration limit set in Belgium for NP/NPE in digestate (Mininni et al, 2015). In comparison the EU has proposed a concentration limit of 50 mg/kg for NP/NPE in sewage sludge applied to land for agricultural use (EU, 2000).

In conclusion there is no reason to retain a lower product contaminant concentration limit of 25 mg/kg for NP/NPEs in the draft Guideline, and increasing the product contaminant concentration to 50 mg/kg does not present an increased risk to soil ecosystems, the wider environment, or human health.

Linear Alkylbenzene Sulphonates (LAS)

Linear alkylbenzene sulphonates (LAS) are the most widely used anionic surfactant. Similar to NPs/NPEOs, LAS is not a single compound and is composed of a mixture of branched isomers with alkyl chain lengths of 10 to 15 carbon atoms, C11 to C13 being the most common. LAS is one of the major ingredients in domestic and industrial detergents and surfactants and therefore is present at relatively high concentrations in sewage sludge.

LAS are easily degraded under aerobic conditions so the concentration of residual LAS in biosolids is highly dependent on the type of sludge produced and the processes within the treatment works. The concentration of LAS in aerobic digested sludge is typically in the range 100-500 mg/kg but it is significantly greater in anaerobic digested sludge's where it can vary between 5000-15000 mg/kg (Jones and Northcott, 2000). Currently there is no data for the concentration of LAS in sewage sludge and biosolids in New Zealand.

LAS rapidly degrades in soil with half-lives of 1-3 weeks. Reviews of the fate and effects of LAS in soil conclude they present a low long term risk to soil ecosystems when amended to soil at recommended agronomic rates (de Wolf and Feijtel, 1998; Jensen, 1999; Norwegian Scientific Committee for Food Safety,2009).

The Product contaminant concentration limit of 1500 mg/kg LAS specified in the draft Guideline for the Beneficial Use of Organic Waste Products on Land was adopted from the limit set by Belgium for LAS in compost or digestate. This is lower than the concentration limit of 2600mg/kg set by the EU for LAS in sewage sludge applied to land for agricultural use (EU, 2000).

Similar to the argument presented to increase the product contaminant concentration limit for NP/NPE in the draft Guideline, increasing the product contaminant concentration for LAS to the proposed EU limit of 2600mg/kg does not present an increased risk to soil ecosystems, the wider environment, or human health.

Diethylhexylphthalate (DEHP)

Phthalates esters are incorporated into plastics as plasticisers and Bis-(2-ethyl-hexyl)-phthalate (DEHP) is the most commonly used worldwide

The Product contaminant concentration limit for DEHP of 75mg/kg specified in the draft Guideline for the Beneficial Use of Organic Waste Products on Land appears to be derived from EU concentration limits summarised in the 2014 CIBR review (Tremblay et al, 2014) which varied from 50 to 100 mg/kg in sewage sludge, compost and digestate.

The EU Working Document on Sludge (EU, 2000) proposes a concentration limit of 100 mg/kg dry matter for DEHP in sewage sludge applied to agricultural land. A 'representative mean' concentration for DEHP obtained from studies of sewage sludge in the USA, Canada, Germany and Sweden is about 90 mg/kg (Duarte-Davidson et al., 1995).

DEHP is rapidly degraded in soil and extremely inefficiently transferred into plants and through foodchains (Duarte-Davidson et al., 1995). Risk assessments completed to date on DEHP applied to land in sewage sludge demonstrate there is no increased risk to soil and aquatic ecosystems, or health risks to either animals or humans when sewage sludge is applied to land at agronomically realistic rates (Duarte-Davidson and Jones, 1996; Wilson et al., 1996, Norwegian Scientific Committee for Food Safety, 2009).

Therefore, increasing the product contaminant concentration limit for DEHP in the draft Guideline to the proposed EU limit of 100mg/kg in biosolids and organic biowaste does not present an increased risk to soil ecosystems, the wider environment, or human health.

Musk fragrances (Tonalide and Galaxolide)

Galaxolide (1,3,4,6,7,8-hexahydro- 4,6,6,7,8,8,- hexamethylcyclopenta (γ) – 2 – benzopyrane (HHCB)) and Tonalide (7-acetyl-1,3,4,4,6-hexamethyltetrahydronaphthalene (AHTN)) are the two most widely used polycyclic musk fragrances and are estimated to represent over 95% of the worldwide market for polycyclic musks. Galaxolide and Tonalide are reasonably hydrophobic chemicals that adsorb to and concentrate in sewage sludge.

The concentration of Galaxolide and Tonalide in sewage sludge is typically in the ppm range (mg/kg) and Galaxolide is almost always present at a higher concentration than Tonalide (Table 4) reflecting its more extensive use in personal care products. The concentration of Galaxolide and Tonalide measured in biosolids from WWTPs in New Zealand is comparable to that in sewage sludge and biosolids from other Western countries (Table 4).

Product contaminant concentration limits of 10 and 15 mg/kg are listed respectively for Galaxolide and Tonalide in organic biowaste within the draft Guideline. These concentration limits have been adopted from those applied by Germany for Galaxolide and Tonalide in sewage sludge applied to agricultural land, but no other member country of the EU has implemented such limits for Galaxolide and Tonalide.

The data in Table 4 demonstrates the concentration of tonalide in biosolids worldwide generally falls below the proposed Product contaminant concentration limits of 15 mg/kg in the draft Guideline. In comparison the concentration of galaxolide in New Zealand biosolids and those from most other countries exceeds the Product contaminant concentration limits of 10 mg/kg in the draft Guideline.

Galaxolide is inherently biodegradable in soil (EU, 2008) and rapidly dissipates from sewage sludge amended soils. For example, the half-life of galaxolide in sludge amended US soils, incorporating a three-month period of freezing to simulate winter conditions, was estimated at 141-144 days (DiFrancesco et al, 2004). A half-life of 105 days was obtained for galaxolide in sludge amended soil in New Jersey USA (Envirogen, 1998), and over 90% of galaxolide had dissipated from soil four weeks after amending biosolids to an agricultural field in Ontario (Yang and Metcalfe, 2006).

Table 4. Concentration of Galaxolide and Tonalide in sewage sludge and biosolids (mg/kg) from New Zealand and other countries

Country	No of WWTP	Sludge description	Galaxolide	Tonalide
New Zealand 2004 ^A	10	Various	1.7- 32.3	0.51- 6.9
Netherlands 1997 ^B	11	Primary	5.4-27	3.3-14
Netherlands 1997 ^B	6	Activated sludge	4.4-63	2.3-34
Netherlands 1999 ^B	8	Primary	6-17	3.7-11.7
Netherlands 1999 ^B	7	Activated sludge	0-21	0-13.5
Netherlands 1999 ^B	2	Digested	19-21	11-13
Germany 1997 ^B	17	Activated	0.1-5.2	0.1-8.9
United Kingdom 2000 ^C	14	Digested	1.9-81	
Denmark ^D	5	Various	11.4-26.5	
Italy 2004 ^E	6	Various	7.7-56	
Spain 2004 ^E	6	Various	12-69	
Greece 2004 ^E		Various	12-39	

Source: ^ACDRP 2005; ^BBalk and Ford, 1999; ^CStevens et al, 2003; ^DMorgensen, 2004; ^EBlok et al, 2005.

A risk assessment of organic contaminants in sewage sludge applied to land in Scotland concluded galaxolide presented a relatively low level of risk to the environment and to human health (WCA, 2014). Similarly, a risk assessment for galaxolide completed for the EU concluded that under normal sludge application conditions the transfer of galaxolide from soil to plants is not relevant and there was no need for risk reduction measures regarding exposure of galaxolide to humans and wildlife from this source to the environment (EU, 2008). The EU risk assessment for galaxolide was completed assuming a concentration of 46.9 mg/kg galaxolide in sewage sludge which is almost five times greater than the Product contaminant concentration limit of 10 mg/kg for galaxolide in organic biowaste in the draft Guideline. Based on the best scientific evidence currently available it is apparent the Product contaminant concentration limit of 10 mg/kg for galaxolide in organic biowaste in the draft Guideline is overly conservative. Based on the outcomes of the EU risk assessment for galaxolide in sewage sludge amended soil it is recommended the product contaminant concentration limit for galaxolide in organic biowaste is increased to 50 mg/kg within the draft Guideline.

Other EOCs.

The CIBR report on EOCs in organic wastes included many other EOCs that have not been included in the Guide, some of which are under the regulatory spotlight in Europe and the USA.

For example, Hexabromocyclododecane (HBCD), a common brominated flame retardant, is now listed in Annex A of the Stockholm convention to which NZ is a signatory. Triclosan (TCS) is the subject of intense

debate and review worldwide and has been banned in many jurisdictions. Regarding phthalate esters there is increasing concern about the environmental and human health impacts of di-isononyl- and diisodecylphthalates which have been produced to replace DEHP.

There is a lack of data on the concentration of these particular EOCs in New Zealand biosolids and biowastes. However, research being undertaken by CIBR will provide data on the concentration of HBCD and TCS in biosolids and biowaste in New Zealand. It is therefore appropriate to exclude these EOCs from the product contaminant list in the draft Guideline until this data is available and the risk these contaminants present to the environment and human health has been assessed.

SUMMARY OF PROPOSED CHANGES TO THE PRODUCT CONTAMINANTS AND CONCENTRATION LIMITS

The recommendations made above for the removal of specific organic contaminants as product contaminants, and modification of product contaminant concentrations for others, are reflected in the modified list of product contaminants and concentration limits in Table 5.

Table 5. Modified Product contaminant concentration limits proposed for inclusion in the Guideline for the Beneficial Use of Organic Waste Products on Land

Contaminant	Parameter	Concentration limit (mg/kg dry weight)
Arsenic		30
Cadmium		10
Chromium		1500
Copper		1250
Lead		300
Mercury		7.5
Nickel		135
Zinc		1500
Nonylphenol and ethoxylates ^A	NP/NPE	50
Phthalate	DEHP	100
Linear alkylbenzene sulphonates ^A	LAS	2600
Musks	Tonalide	15
	Galaxolide	50

^A comprising the sum of technical nonylphenol, NPE10 and NPE20 equivalents

^B comprising the sum of technical C11-C13 homologues and corresponding mixture of isomers

These recommended modifications are based on best available scientific knowledge and reflect the relatively low risk the listed organic contaminants present to the environment or human health from the application of biowaste to land.

Adopting EU limits for the concentration of NP\NPE, DEHP and LAS in sewage sludge applied to agricultural land within the draft Guideline provides the advantages of harmonising contaminant limits with countries that are continuing to reassess the risk organic contaminants in biosolids present to the environment and human health. Any future changes to contaminant limits in sewage sludge implemented by the EU can be justifiably incorporated into future revisions of the New Zealand Guideline for the Beneficial Use of Organic Waste Products on Land.

Similarly, if the outcomes of future research undertaken in New Zealand or overseas demonstrate other organic chemicals in biosolids and organic biowaste represent a high risk to the environment or human health, or our understanding of the risk presented by the organic chemicals in the current list changes, of they can be integrated into

Similarly, as research provides new information on the risk organic chemicals in biosolids and organic biowaste present to the environment or human health it should be evaluated for incorporation into the New Zealand Guideline for the Beneficial Use of Organic Waste Products on Land.

RECOMMENDATIONS FOR THE ANALYSIS OF EOCs IN ORGANIC BIOWASTE

The commercial analytical testing laboratories in New Zealand have the necessary laboratory equipment and analytical instrumentation to analyse the modified list of organic product contaminants proposed in this report. These laboratories have the expertise and capability to develop and validate a targeted organic contaminant protocol to analyse the specified organic contaminants within organic waste products.

The different properties of the organic chemicals in the modified list of EOCs in Table 5 means they are unable to be extracted by a common solvent and instead it will be necessary to apply two separate extraction methods. The extraction of NPs/NPEs, DEHP, and tonalide and galaxolide from organic biowaste can be accomplished with standard solvent extraction methods for semi-volatile organic contaminants using dichloromethane or a mixture of acetone and hexane as the extracting solvent.

Due to their high polarity the extraction LAS from organic biowaste will require the use of methanol as the extraction solvent.

Extraction techniques recommended and approved by the USPEA including soxhlet extraction, sonication extraction, and pressurised liquid extraction are all suitable for extracting the EOCs in the modified product contaminant list from organic biowaste.

The extent to which the solvent extracts of organic biowaste will need to be purified before instrumental analysis will be dependent upon the extraction method and solvent that is employed, and the properties of the biowaste being analysed. However, the product contaminant concentrations for the proposed EOCs are relatively high compared to normal environmental concentrations, and as such it may be possible to overcome the negative effects of co-extractive matrix components by simply diluting the raw sample solvent extracts before analysis.

Following extraction from organic biowaste the specified EOCs can be analysed using gas chromatography-mass spectrometry (GCMS) and/or liquid chromatography-mass spectrometry (LCMS).

Analysis of the listed EOCs by LCMS provides the advantage that it would not be necessary to chemically derivatise any of the EOCs prior to analysis and it may be possible to analyse all five compounds/classes of EOCs in a single chromatographic run.

Analysis of LAS by GCMS will require chemical derivatisation of LAS to their respective trifluoro-sulphonates or sulphonated alkyl esters using appropriate procedures.

Analysis of LAS using the colorimetric methylene blue assay to obtain total anionic surfactant content is not recommended as this will have limited application to organic wastes due to the myriad of interferences it is subject to.

With the appropriate choice of injection solvent and instrumental and chromatographic conditions the analysis of NP/NPE, DEHP, galaxolide and tonalide can be accomplished by GCMS in a single chromatographic run without derivatisation. Alternatively, DEHP, NP1EOs, NP2EOs, galaxolide and tonalide can first be analysed and the extract subsequently derivatised for the analysis of technical-NP as the corresponding alkyl, alkylhalide, or alkylsilyl ethers.

The combined cost to analyse the organic contaminants in the modified Product Contaminant list at the specified concentration limits should be somewhat less than the previous combined cost to analyse total PCBs, Dioxin TEQ, and the chlorinated organic contaminants previously specified in the 2003 Biosolids Guidelines.

Specific recommendations regarding quantitating and reporting of technical NP/NPEs and LAS residues

As discussed previously NP/NP1EOs/NP2EOs and LAS are not single chemicals and are instead technical industrial mixtures comprising a series of branched alkyl chain isomers in the case of NP/NP1EOs/NP2EOs, and for LAS a series of alkyl chain homologues containing a series of isomers.

Using standard GCMS analysis up to 22 individual NP compounds can be detected in Technical mixtures of NP but the resulting total ion chromatogram is typically dominated by 8 to 12 peaks.

The linear alkyl chain of LAS consists primarily of C10 to C13 homologues, typically in the ratio of 13:30:33:24, and commercial products commonly contain around 20 individual compounds.

NP/ NP1EOs / NP2EOs are most often analysed and reported as “equivalents” of the corresponding technical mixtures. In the case of technical-NP common mass ions selected from the dominant 8 to 12 peaks in a chromatogram of a technical-NP mixture are acquired and the mass contribution of each peak determined to produce calibration curves for the dominant peaks. The mass ion responses obtained from analysis of a sample are integrated and quantitated against the calibration curves. The masses obtained for each individual peak are summed, and this “total” is reported as the mass of technical-NP equivalents. The same approach is applied for the analysis of the corresponding mixtures of NP1EOs and NP2EOs.

The same approach is used for the analysis of LAS, but LAS is typically reported as equivalents of the individual C10, C11, C12 and C13 homologues. This procedure has persisted from the original HPLC analysis methods for LAS that were able to resolve the C10 to C13 homologue series, but not the individual isomers within each homologue group.

Modern LCMS instruments will be able to resolve the individual LAS isomers within each homologue group on the basis of mass-ion differentiation, and therefore LAS can be reported as both the individual isomers and their respective total within each homologue group.

Following chemical derivatisation of LAS, the increased chromatographic resolution provided by glass capillary gas chromatography columns enables the individual isomers within each homologue groups of commercial mixtures of LAS to be analysed by GC-based methods.

Analytical standards of representative industrial mixtures of NP/NP1EOs/NP2EOs and LAS are available from providers of specialist analytical standards. These same suppliers often provide standards of selected individual compound isomers which should be purchased and used to validate the performance of the analytical method. Similarly, isotopically labelled standards available from specialist suppliers

should be used as internal and recovery standards to improve the performance of the analytical method, and to normalise the effects of signal enhancement and/or suppression arising from the presence of residual co-extracted matrix in solvent extracts of organic biowaste.

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7 CONSULTATION RESOURCES

This section contains useful information on consultation practices and maori beliefs. Also refer to The Ministry for the Environment everyday guide to the RMA: Consultation for resource consent applicants at <http://www.mfe.govt.nz/>.

7.1 CIBR-LEI COMMUNITY ENGAGEMENT FRAMEWORK

This section is available as a separate report: The CIBR/LEI Community Engagement Framework for Biowastes which is available as a separate download [here](#).

7.2 TAPU TO NOA REPORT

This section is available as a separate report: “From Tapu to Noa – Māori Cultural Views on Human Biowaste Management” which can be downloaded [here](#).

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PUBLIC COMMENT

The CIBR/LEI Community Engagement Framework for Biowastes



Photograph courtesy of Te Rūnanga o Ngāi Tahu.

February 2016

Virginia Baker, James Ataria, Joanna Goven, E.R. (Lisa) Langer,
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Centre for Integrated Biowaste Research

L O W E
Environmental
I m p a c t

REPORT INFORMATION SHEET

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SIGNED OFF BY

A photograph of a handwritten signature in black ink on a light-colored background. The signature appears to read 'Horswell'.

JACQUI HORSWELL

DATE FEBRUARY 2016

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Disclaimer

The opinions provided in the Report have been provided in good faith and on the basis that every endeavour has been made to be accurate and not misleading and to exercise reasonable care, skill and judgment.

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Centre for Integrated Biowaste Research



The CIBR/LEI Community Engagement Framework for Biowastes

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EXECUTIVE SUMMARY

Stakeholder and wider community consultation is recommended for Resource Management Act 1991 consenting and by the Local Government Act 2002 when making decisions on behalf of the community. In addition, the Treaty of Waitangi (1840) guides partnerships with Iwi for environmental management. However, such engagement can be challenging without a robust transparent process in place.

In the case of waste management issues, there are often significant existing infrastructure investments. Therefore, decisions can be heavily driven by technical criteria and there is a limited range of options that are feasible. However, community input can improve the quality of policy being developed, making it more practical and relevant. It can ensure that services are delivered in a more effective and efficient way for a local community and can result in cost and time savings by addressing community issues much earlier in decision-making.

The Centre for Integrated Biowaste Research (CIBR), a multidisciplinary research organisation, and Lowe Environmental Impact (LEI), a science and engineering company, have developed a Community Engagement Framework to assist waste producers and regulators (regional, district and city councils) to more effectively undertake community consultation with respect to the discharge of biowastes to land in New Zealand. In the context of this framework, biowastes are described as solid and liquid organic biodegradable waste, including biosolids, organic industrial waste, agricultural waste, kitchen/food waste, green waste, sewage effluent and greywater.

CIBR researchers developed and implemented a number of community engagement methods and have evaluated them for their ability to support integrated decision planning and improve science, policy and community engagement. LEI brings practical experience and processes required to satisfy regulatory and environmental requirements. Together, their collective experience has developed this Community Engagement Framework for the management of biowastes that provides a pathway to meet the requirements of the Resource Management Act, Local Government Act and the Treaty of Waitangi.

The CIBR/LEI Community Engagement Framework provides a clear and manageable process. It is based on a number of different factors that support 'good practice' and processes required to satisfy regulatory and environmental requirements of preferred options. The framework utilises the quadruple bottom line (QBL) approach to decision-making where environmental, social, cultural and economic factors are thoroughly considered and outlines how two-way communication can be facilitated by interactive stakeholder workshops, hui or public meetings. These community meetings provide the mechanism that allows regulators, technicians, engineers, council staff, elected members and community members to identify the key 'community' values that a 'technical' solution will need to align with, as well as to elicit relevant knowledge from the community. Importantly the process helps build shared understanding between different stakeholders, strengthens council and community relationships, builds greater trust and confidence in the decision-making process and is showing improved buy-in by communities.

1.0 Purpose

Centre for Integrated Biowaste Research (CIBR) researchers have evaluated and tested community engagement methods with urban and rural communities since 2003 to collectively determine sustainable biowaste management. Lowe Environmental Impact (LEI) engineers have tested a practical approach to community engagement over the last 15 years. As their respective community engagement processes have many areas of commonality, this has led to the development of a joint CIBR/LEI Community Engagement Framework for biowastes, which is recommended for use by the waste sector. This joint framework is underpinned by significant research evidence (see Reference section) and practical field experience.

The CIBR/LEI Community Engagement Framework aims to assist waste producers and regulators (regional, district and city councils) to more effectively undertake community consultation with respect to biowastes¹, such as the discharge of biosolids² to land. The framework has been designed to support the *Guidelines for the Safe Application of Biosolids to Land in New Zealand* (New Zealand Water and Wastes Association, 2003); to enable the greater involvement of communities in decision-making; and to enhance beneficial re-use of biowastes, such as biosolids.

More specifically, the framework aims to:

- provide a manageable process for integrating technical and social factors into the management of biowastes;
- provide a mechanism to identify issues of local significance, as well as diverse community concerns and interests; and
- encourage regulatory authorities to adopt a consistent approach to community consultation.

Utilisation of the framework can:

- create an awareness within the community of the potential benefits and risks of biowastes use; and
- help build shared understanding between different stakeholders, strengthen council and community relationships, and build greater trust and confidence in the decision-making process.

2.0 Background

Waste management has long recognised the importance of ‘public acceptance’ in the success of any beneficial re-use of biowastes, but this has focussed on public ‘education’, rather than public involvement in decision-making. This is often based on assumptions that more ‘technical’ information will change people’s values and viewpoints (Goven and Langer, 2009). However, more education and information are neither always effective nor necessarily relevant. There is increasing recognition in the sector that the ‘technical’ expert estimations of ‘actual (technical) risk’ may not take into account the factors important to how individuals and communities may see risk.

Such factors, sometimes called ‘outrage’ factors include (e.g., involuntary or out of people’s control); not reversible (e.g., persistent pollutants are permanent additions to soils); unknowable (e.g., difficulties of identifying fate/effects of waste components in particular environments); or having delayed effects (some effects from the waste may not be evident

¹ Solid and liquid organic biodegradable waste, including biosolids, organic industrial waste, agricultural waste, kitchen/food waste, green waste, sewage effluent, greywater etc.

² Treated or stabilised sewage sludge.

immediately and may affect future generations). Other important factors that can impact upon people's willingness to consider re-use options include the place-based and deeply held intrinsic environmental values that inform tikanga and Māori knowledge frameworks (Marsden, 2003; Ataria, et al., 2016).

Issues relating to wastes, such as wastewater and sewage sludge, are strongly determined by technical criteria and constraints (e.g., existing infrastructure sites, systems and networks of pipes to transport wastewater, and the systems are that expensive to replace, maintain, change or redesign). Managers of waste systems may fear that involvement of communities in management decisions may unrealistically raise community expectations, and may expose such diverse views that a decision is unable to be made. However, community input can improve the quality of policy being developed, making it more relevant and practical. It can ensure that services are delivered in a more effective and efficient way for that community and can result in cost and time savings by addressing community issues much earlier in decision-making.

This framework provides an approach to incorporating community knowledge, concerns and views into 'technical solutions' that are justifiable and acceptable, and enhancing sustainable management of biowastes.

3.0 Statutory requirements

3.1 Local Government Act 2002

Local authorities have a general requirement under Part 6 of the Local Government Act 2002 to undertake consultation in relation to decisions made on behalf of the client community. This includes funding decisions for public works, in which case consultation will need to be with all of the rate-paying public, or at least those members of the rate-paying public with the potential to be exposed to any liability for costs.

3.2 Resource Management Act 1991

Under the Resource Management Act 1991 (RMA), there is no direct statutory requirement for consultation with any other party. However, it recommends stakeholder and wider community consultation when making decisions on behalf of the community. It is best practice to engage with persons considered by the consenting authorities to be affected parties (i.e. community stakeholders) and to ensure that consultation with affected parties starts well before consent applications are lodged.

3.3 Treaty of Waitangi 1840

The Treaty of Waitangi 1840 guides partnerships with Iwi for environmental management; and the increasing number of Treaty of Waitangi Settlement Acts often prescribe the nature of relationships between local government and mana whenua³ entities and how the environment is to be managed. The relationship between local government and Iwi is especially important⁴.

³ Mana whenua describes the local hapū within a designated area or district who have sovereignty or mana of that locality that in turn is derived from their connection to ancestral occupation of that area.

⁴ Section 6 of the RMA sets out the 'Matters of National Importance' that shall be recognised and provided for by all persons exercising functions and powers under the Act and including "the relationship of Māori and their culture and traditions with their ancestral lands, water, sites, wāhi tapu, and other taonga".

As both a Treaty partner and key stakeholder, Iwi and rūnanga have a very keen interest in being involved in biowaste, water and environmental decision-making.

4.0 Approaches to community engagement

There are many ways to approach community engagement.⁵ The International Association of Public Participation (IAP2) has developed a useful Spectrum (Figure 1) outlining five different approaches, along with their associated goals, promises, and tools. One size does not fit all; it is important to think about your community’s issue and the approach that fits best with your purpose.

IAP2 PUBLIC PARTICIPATION SPECTRUM

INCREASING LEVEL OF PUBLIC IMPACT				
INFORM	CONSULT	INVOLVE	COLLABORATE	EMPOWER
Public Participation Goal:	Public Participation Goal:	Public Participation Goal:	Public Participation Goal:	Public Participation Goal:
To provide the public with balanced and objective information to assist them in understanding the problems, alternatives and/or solutions.	To obtain public feedback on analysis, alternatives and/or decisions.	To work directly with the public throughout the process to ensure that public concerns and aspirations are consistently understood and considered.	To partner with the public in each aspect of the decision, including the development of alternatives and the identification of the preferred solution.	To place final decision-making in the hands of the public.
Promise to the Public:	Promise to the Public:	Promise to the Public:	Promise to the Public:	Promise to the Public:
We will keep you informed.	We will keep you informed, listen to and acknowledge concerns and provide feedback on how public input influenced the decision.	We will work with you to ensure that your concerns and aspirations are directly reflected in the alternatives developed and provide feedback on how public input influenced the decision.	We will look to you for direct advice and innovation in formulating solutions and incorporate your advice and recommendations into the decisions to the maximum extent possible.	We will implement what you decide.
Example Tools:	Example Tools:	Example Tools:	Example Tools:	Example Tools:
<ul style="list-style-type: none"> • fact sheets • web sites • open houses. 	<ul style="list-style-type: none"> • public comment • focus groups • surveys • public meetings. 	<ul style="list-style-type: none"> • workshops • deliberate polling. 	<ul style="list-style-type: none"> • citizen advisory committees • consensus-building • participatory decision-making. 	<ul style="list-style-type: none"> • citizen juries • ballots • delegated decisions.

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Figure 1: IAP2 Approaches for Community Engagement.

4.1 New Zealand specific research

Since 2003, CIBR researchers have worked with community groups and key regulatory and industry stakeholders to derive collaborative management systems and technical solutions that are fit for New Zealand purposes and best practice.

Outcomes of the CIBR research suggest that neither the **Inform** nor the **Consult** approach described in the IAP2 framework are likely to be successful in this domain as they do not encourage constructive community engagement. The **Involve** approach permits more

⁵ See References for some key publications in this field.

constructive engagement, but is not as likely as the **Collaborate** approach to generate innovation, learning, agreement, and commitment to the selected solution. CIBR research suggests that the **Collaborate** approach is the best approach to work towards for community engagement, when the necessary commitments can be made. It allows an open dialogue without a preconceived agenda to follow a particular course of action or a narrow range of options. The **Empower** approach will usually not be appropriate in the biowaste management context for technical and legal reasons. (See Appendix 1, where these approaches, and their pros and cons, are described in greater detail.)

Consult, Involve and **Collaborate** typically involve 'face-to-face' community meetings or workshops. For Iwi, the 'face-to-face' or 'kanohi te kanohi' approach is vital for building and maintaining constructive relationships. Be aware that some Iwi and community members may feel 'consultation fatigue' or may be cynical because previous consultations seemed to have little influence on the decisions.

5.0 The CIBR and LEI community engagement framework

5.1 The quadruple bottom line

The CIBR/LEI Community Engagement Framework brings together a number of different factors that support 'good practice', including the quadruple bottom line (QBL) approach where environmental, social, cultural and economic aspects are explicitly considered to generate sustainable solutions. The QBL decision criteria process helps provide a structured way to identify key community concerns and priorities to ensure that any decision is based on shared understandings and a strong overlap of technical and community criteria. This approach is recommended by the International Council for Local Environment Initiatives (ICLEI) as the most appropriate planning and reporting format for local governments for sustainable development. A globally adopted definition for sustainable development is development that "meets the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland Commission, 1987). It has long been recognised that there are three bottom lines (Triple Bottom Line)—ecological, social and economic sustainability—that must be balanced and considered. However, indigenous peoples throughout the world have had an understanding of the principles of sustainability and have lived sustainable lifestyles, for millennia, thus a fourth dimension has been added to the framework – spiritual or cultural considerations (Scrimgeour & Iremonger, 2004; Swanson & Zhang, 2012; Hikuroa et al. 2010; Sengupta et al. 2015). The CIBR social science research team have pioneered the application of the QBL to the waste sector in New Zealand.

There are different ways to present the QBL and, due to its complexity, graphics are helpful. Two examples are given below. Animating the graphics is also a useful way to explain how the QBL works, so animated versions of the graphics shown below are available on the CIBR and LEI websites ( www.cibr.esr.co.nz; www.lei.co.nz). The graphic of choice will depend on the audience and the person facilitating or chairing the community meetings.

5.2 The CIBR QBL Footprint approach

CIBR researchers conceptualise community engagement as an exploration of the four elements of the QBL (environment impacts, social views, cultural acceptance and economic cost) in order to attain sustainable solutions. They have found it useful to represent the process as a decreasing QBL 'footprint' (Figure 2). Community engagement clarifies the threshold between the acceptable and the unacceptable across the four elements and helps to identify solutions that have an overall 'footprint' of acceptability. The goal for biowaste management is to move from what is currently often a large footprint to a smaller, more acceptable one.

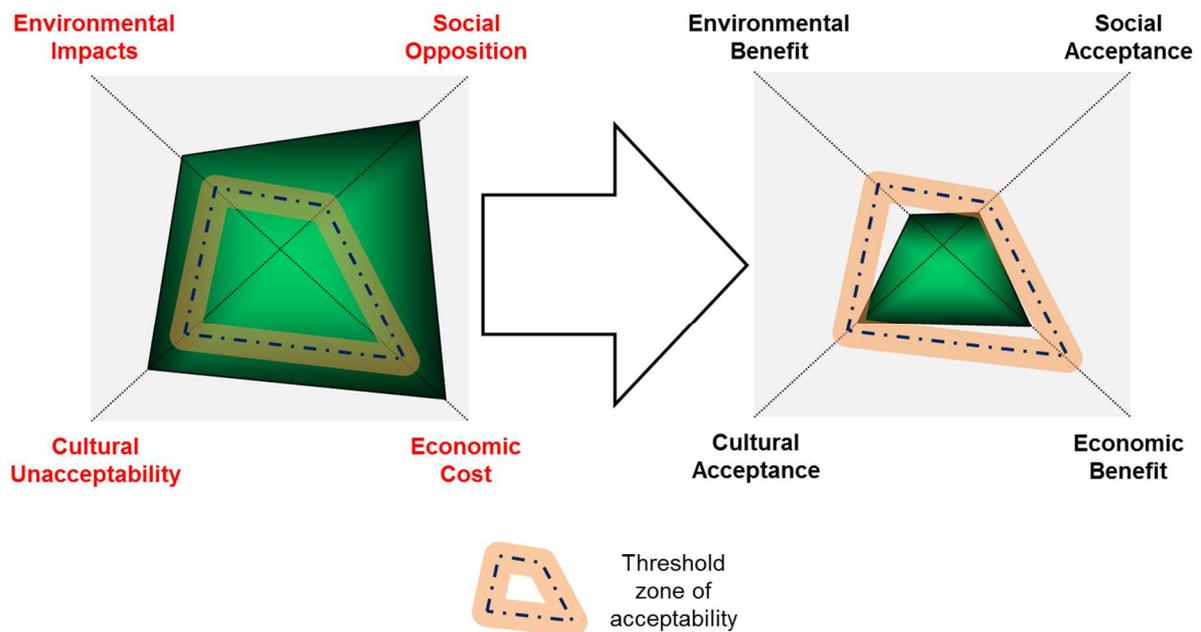


Figure 2. The Quadruple bottom line footprint. Reducing the size of the footprint via dialogue, technology and new knowledge.

5.3 The LEI Solid Stool Concept

LEI have developed a 'Solid Stool Concept' in their biowaste management projects with Councils and small-medium communities (e.g., Masterton and Foxton). The 'Solid Stool' builds on the QBL approach, but includes additional practical steps required for resource consenting, system operation and management. The concept involves a two-step process; the first step is working with the community to develop sustainable management options. The second step is the regulatory approval of the preferred options. The first step is essentially a Local Government Act process of engaging with the community and working out what is best, and the second is a Resource Management Act process where the preferred option is approved.

Step 1: A key aspect to the Solid Stool Concept is a 'Vision' which is developed at the onset of the project by the community and Council. LEI have found that presenting the QBL as a 'stool' provides an easy to understand concept and helps gain buy-in from the community on the need for each stool leg (or QBL consideration) to be considered as important. Failure to consider one or more values results in the overlying stool seat becoming unstable. The seat of the stool represents the practical journey from identifying values and issues, to developing options, identifying a preferred option and then implementing that option, these include:

- Gather Information
 - Which enables an understanding of the background of issues, including:
 - Characterisation of the waste stream
 - Identifying limitations (e.g., material, site, environment etc.)
 - Investigations:
 - What do we know and what don't we know?
- Design
 - Once background work is complete:
 - Develop a range of technical options and modifications
 - Identify preferred option(s)

- Consent
 - What Governance/community approval would be required for preferred option?
 - What regulatory approval is required?
- Operate and Manage
 - How will it look and how will it be managed?

Step 2: In the second step, engagement is around the effects of the preferred option, this will include investigating environmental, social/cultural impacts and affordability, i.e. the QBL. The solid stool can once again be used to aid these discussions with the community. As part of the RMA process it must be demonstrated that alternatives have been considered (i.e. Step 1). In Step 2 the seat of the stool is focussed on the regulatory requirements of the RMA, i.e. what is required to obtain the appropriate consents. This could include: gathering data for an Assessment of Environmental Effects (AEE) and Cultural Impacts Assessment (CAE); preparations of a Conceptual Design, and Management and Monitoring Plan.

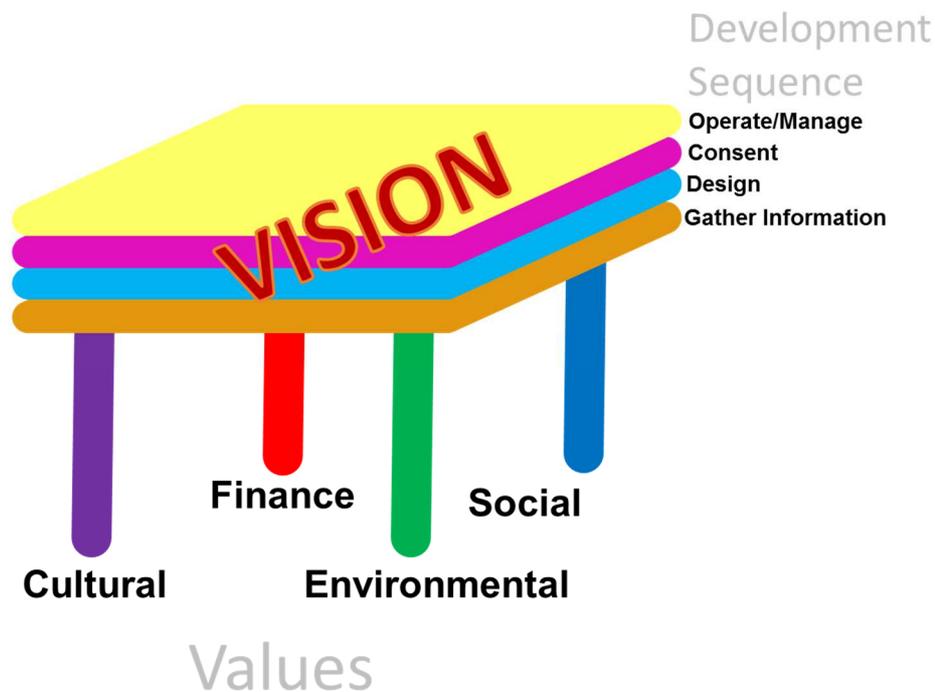


Figure 3. The solid stool concept.

5.4 Grounding Principles

The CIBR/LEI community engagement framework is underpinned by seven grounding principles:

5.4.1 Early

Engage as soon as possible, when there is still the flexibility to make changes to address issues raised by interested and affected people. Early engagement is likely to be more successful than engagement within a crisis. If engagement is left too late, people will think

there is no intention of taking their views into account. However, if consultation is *too far* in advance, too few may be interested (depending on the issue).

5.4.2 *Transparent*

Be open about what the project wants to achieve, what scope there is within the project to change certain aspects of the proposal and why there might be elements that may not be able to be changed.

5.4.3 *Open Mind*

Keep views open to the responses people make and the benefits that might arise from engagement.

5.4.4 *Two-Way Process*

Engagement is intended as an exchange of information and requires both the project team and community participants to put forward their points of view and to listen to and consider other perspectives.

5.4.5 *Genuine*

While the length of time available to engage is not open-ended or never-ending, engagement should not be seen merely as an item on a list of things to do that should be crossed off as soon as possible.

5.4.6 *On-Going*

It may be that engagement, or at least communication, will continue after the consent application has been lodged, or even after a decision has been made.

5.4.7 *Agreement*

Engagement does not mean that all parties have to agree on a proposal, although it is expected that all parties will make a genuine effort to strive for such an agreement. Even when agreement is not reached on all issues, it can be useful for points of difference to become better defined.

5.5 Step-by-step process

In this section a step-by-step process is outlined for community engagement that can aid the development of good working relationships with the community. This process will provide more robust decisions, with a good evidence base of community values and inputs.

5.5.1 *Step 1. Know your community, issue and mandate*

A. KNOW YOUR COMMUNITY

Get to know the local community and especially any mandated Iwi/hapū organisations or organisations that you believe would have an interest. Notify them of the issue, even if you are not statutorily bound to do so, because this is good relationship-building and shows respect and good faith.

Undertake an analysis of key stakeholders (e.g., affected people, environmental groups, local businesses, etc.) and know whom to involve. Have defensible criteria for why the invitation includes some people and not others, and be inclusive rather than exclusive. This 'scoping'

process is useful in building relationships and trust. If you use this process there is less chance of being surprised by someone who opposes decisions later on.

B. KNOW YOUR ISSUE

Know the technical facts – waste characteristics, site geology, hydrology, monitoring results etc. Be aware that some members of the community will also have expertise that they are willing to share. For example, there might be retired engineers in your community, or people with specific local historical, cultural or environmental knowledge. Many in the community will look to the scientists and engineers as the experts and will want the organisation to show the lead in suggesting viable solutions to which they can then respond.

C. KNOW YOUR MANDATE

Know the limits of the engagement and decision-making process, and know the constraints, so that you can accurately outline the process timeline and what will happen next. Being open and transparent about budget and other limits, and who will actually make the final decisions and when, are important items in the initial conversations. Are the options fairly restricted, or is there scope to modify or do things differently? Can you consider new ideas and approaches?

Be flexible and ensure that staff are prepared to modify their own views by responding and incorporating community ideas. Normally the burden of community member involvement is borne by them so they often may want to know how their information is being used and to what extent it will make an impact. Or are you consulting simply to keep people informed, to test a predefined solution, or to build support for an outcome predetermined by regulators? If so, it is important to acknowledge this to yourselves and to the community.

5.5.2 Step 2. Disseminating Information

Getting the community involved will require dissemination of information. Effective communication is about ensuring that information is provided in a way that is clear and concise and reaches its target audience. Effective communication should follow these principles:

- **Relevant.** There is a lot of information freely available. It is important to make sure that all information provided is necessary and relevant;
- **Clear and Concise.** Information needs to get key messages across clearly and efficiently to capture peoples' attention;
- **Targeted.** Information needs to be targeted to its intended audience;
- **Accessible.** Innovative methods of information dissemination should be considered. In addition to more traditional methods such as newspaper and radio advertising, other methods may be appropriate, such as a project website, email updates and social media.

5.5.3 Step 3. Stakeholder and community dialogue/workshops

This step provides the mechanism to identify issues of local significance, as well as diverse community concerns and interests through two-way dialogue. It allows regulators, technicians, engineers, council staff, elected members and community members to identify the key 'community' values that a 'technical' solution will need to align with, as well as to elicit relevant knowledge from the community.

Every community has some people that have strong views and will readily make these views known to others. A robust engagement process can include those with strong views in a

structured and coherent way, while ensuring that the more reticent also have an opportunity to voice their views. Including these views ensures that those more passionate about the issue have a say, are listened to and that these people listen to the viewpoints of others. If people have a greater understanding of a complex issue and have been involved in a positive process they may be less likely to contest the decision in future. They should nonetheless be reassured that their involvement in the engagement process does not curtail their participation in later statutory processes.

You will need at least three meetings to allow time to present the background information and the potential options, provide the opportunity for feedback and further investigate the ideas or questions put forward. This will signal a commitment to include community inputs and provide a transparent process for feedback.

Each workshop has several steps, and 1½ hours is the minimum time required. It is important to be flexible: it may not be possible to get through all the steps, and tasks may need to be modified as the workshop progresses. A sample run sheet for workshops can be found in the Appendix 2.

Meeting 1:

- Understand the journey – what is the purpose of the engagement? What do you want to achieve? What are the parameters and constraints?
- Understand the background – what are the technical facts, waste characteristics, geology, hydrology, monitoring results, etc. Presentations need to be short, informative and focused on key information while pitched at the knowledge level of the group.
- Understand the options – what is the range of options available.
- Canvas from the group if there are other options that might be considered and if there are any questions (e.g., about the waste, the relevant environment or the options) that need to be answered before a decision can be made.
- Introduce the concept of the QBL and the need for balancing differing and often competing viewpoints of sustainability.
- The outcome of the first meeting is a greater collective detailed knowledge of issues and options, as well as awareness of what additional information needs to be obtained and who is missing and needs to be included in future dialogue.

Meeting 2:

- Present information answering any outstanding questions from Meeting 1.
- Review the QBL approach, using a brief ‘workshop’ process to raise questions/issues, which allows for community members to identify the key ‘community’ values that a ‘technical’ solution will need to align with. Much of the discussion should be focused on the environmental, cultural, social and economic QBL categories. There is no predetermination of what each category might mean as it is important that the community determine what these four areas mean to them. It is important to be flexible about the QBL categories. For example, a community may want to identify ‘spiritual’ values and concerns as a fifth criterion.
- Elicit feedback and community evaluation of options and arrive at a preferred selection of options. This can be done using a simple voting system.
- The outcome of this stage is typically a community nominated preference(s) or option(s) to a way forward with a number of questions or issues that may need to be answered or addressed at the third meeting.

Meeting 3:

- Review the process to date.
- Present information answering questions that may have arisen in Meeting 2.
- Discuss the short list of options produced in Meeting 2 and elicit a final option or options, again using a simple voting system.

- Discuss whether or to what degree the community's preferred option(s) will be implemented, explaining in detail which parts if any cannot be implemented and why and/or how the preferred option(s) will be implemented and what can be expected. Be sure there is an opportunity for community responses and consideration of community views, objections and suggestions.

5.6 Conceptual design

Based on the previous three meetings, appropriate conceptual designs of the preferred option(s) are typically prepared, including the rationale for selecting this design and the anticipated operational, regulatory and environmental requirements.

A further community meeting may be required at this stage to refine the Conceptual Design. Based on the preferred option, there will be a need to identify the issues to be addressed in meeting planning and consenting requirements (see Statutory requirements above). At this stage of the process newspaper/website articles may be appropriate communication methods.

5.7 Guidelines for successful engagement

PLANNING IS CRUCIAL: Plan the process, steps and timing, so you have clear goals and steps. Outline these at the start so everyone has a common understanding of the process, steps and outcomes you want to achieve.

SCHEDULE CAREFULLY: Help ensure a good turnout by checking that the workshop does not clash with other festivals or community events.

REPRESENTATION: The quality of the data gathered is always dependent on who attends on the day. With most engagement processes, it is difficult to determine if the people that attend on the day represent the range of interests held by the wider community, so invite a good range of people or representatives from key interest groups. Emphasise that the workshop is only one form of community input and feedback, and that there will be other opportunities for feedback in the wider decision-making process. The more thoroughly the process is documented (e.g., minutes) and that documentation made available to the wider community, the greater the chances that the community as a whole will see value in the process and the decision reached through it.

MANAAKITANGA: Warm hosting and sharing food will bring participants together to dialogue constructively and minimise tensions or disagreements. Invite the local Iwi representatives to perform a karakia (prayer) then introduce the process. In closing, reiteration of next steps, feedback and larger decision process are respectful and informative.

PHYSICAL LAYOUT: An open area with tables arranged in a café style that allow small breakout groups is recommended so that people can work together. This helps break down the distinction between regulators, council and community that more formal rows of seating and speakers might convey.

FACILITATION: Consider having an independent facilitator to manage conflict if you suspect that workshop dynamics and personalities could get challenging. If appropriate, the workshop or hui should open with a karakia, followed by introductions of community leaders, kaumātua and the technical team. This should be followed by outlining the process and the rules for the day (e.g., listening respectfully to others) and clarifying expectations.

CIRCULATE: Community meetings work best with technical staff and expert advisors circulating to answer questions, share their knowledge and listen to the discussions. This can

strengthen understanding between staff and community participants, enable access to staff or expert knowledge to address some knowledge gap questions on the day to inform their discussions and test potential solutions more quickly.

SMALL GROUP PROCESS: Consider whether homogenous or heterogeneous (or both/alternating) small groups are appropriate. It is essential to ensure all voices are captured and all points acknowledged; ‘park’ points that are not immediately relevant to come back to and check for relevance later—have a blank sheet or other area set aside for this. Small groups of stakeholders can brainstorm a range of issues: for example, which concerns, values or aims are most important to them; which questions or knowledge gaps need follow-up; the relevance of their own local environmental knowledge; etc. It is good to rotate/circulate small groups if time permits so participants can appreciate that there are alternative values and different viewpoints to consider.

WHOLE GROUP PROCESS: The key points derived from small group discussions can be fed back to the wider group. Voting on values or options can take place by providing each participant with coloured dots (with or without priority ratings) and ask them to place their dots beside the values they feel are most important or options that are most preferred. A private voting process could be considered if an open process may influence responses. Examining tallied scores for majority support, contradictions, tensions or areas where trade-offs might be needed provides instant answers and feedback on decision-making.

PERSEVERANCE: Don’t end the workshop early if things get difficult – stay engaged and try to move things on. Don’t turn anyone away from a workshop. Even if someone has an antagonistic relationship with council staff, other community members in the group will be very quick to help moderate.

MEETING SUMMARY AND NEXT STEPS: Record the meeting in the form of comprehensive minutes; this enables an accurate record of what was discussed and any agreed next steps and or outcomes. As well as disseminating the minutes to the meeting participants, make them publicly available so that those who could not attend the meeting can be part of the process if they wish to attend the next meeting. The minutes should also describe what the next steps in the process will be.

6.0 Conclusions

There is a need for sustainable biowaste management solutions that recognise complex environmental, social, cultural and economic relationships and factor the latent and cumulative environmental effects that may occur at a catchment or regional scale. The CIBR/LEI Community Engagement Framework helps address this complexity by eliciting relevant environmental, social, cultural and economic knowledge; enabling shared understanding between different stakeholders; and strengthening council and community relationships, which can build greater trust and confidence in the decision-making process. The framework brings together 15 years of expertise from leading edge research and technical experience to produce an easy to follow step by step process to community engagement following a quadruple bottom line approach.

This enabling approach to consultation with community stakeholders is showing improved buy-in to biowaste projects by their respective communities, rather than a confrontational approach. Enabling communities to take ownership gives them the power to decide what they can afford and the trade-offs they are prepared to accept; which in turn will lead to an increased beneficial re-use of biowastes.

7.0 Further information

Further information on the CIBR/LEI Community Engagement Framework can be found at: www.cibr.esr.cri.nz or www.lei.co.nz

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Appendix 1: Applying IAP2 approaches to biowaste issues

Inform:

- One-way communication
- Often the default mode of engagement for waste infrastructure issues
- Not suitable for introducing change or getting 'buy-in'
- Provides limited opportunities for feedback and any feedback likely to be given by those with strong opposing views
- Typically low initial cost and useful for initial awareness-raising.

Examples: Notice of the resource consent intentions in a public newspaper; sending letters to affected parties; newspaper articles, leaflets, newsletters, written reports; posting information on council websites; social media, open days and school tours.

Consult:

- Often driven by regulatory conditions, e.g., statutory requirements for consultation
- Often used to ratify a pre-determined solution, or to obtain community feedback on selected pre-defined options
- Fits the 'business-as-usual' dynamics for wastewater decision-making, where there are strong technical and bureaucratic constraints
- Can evoke negative reactions from participants, as the opportunities for influence are highly constrained
- Lack of (perceived and/or real) ability to influence can result in a low turnout to public meetings
- Not recommended, except as a starting point.

Examples: Notification in the local newspaper or by mail to affected parties with an invitation for written submissions; surveys; public meetings.

Involve:

- Good approach to begin community engagement
- Signals a clear promise or commitment to include community inputs where possible
- Provides a transparent process for feedback to show how different viewpoints were considered
- Enables addressing questions on the day and testing potential solutions more quickly
- Enables relationship-building and gaining a better appreciation for the issues, different viewpoints, constraints and trade-offs
- Helps generate shared ownership for local solutions and innovations
- May raise expectations for greater community influence in decision-making, so it is important to have a good mandate and buy-in within council.

Examples: Interactive stakeholder workshops, working groups or hui with at least two meetings to give time for feedback and to further investigate the ideas or questions put forward. These meetings work best with 'experts on tap' so that council technical staff, local engineers and scientists can answer questions and circulate around working groups to share their knowledge and listen to the discussions. The 'involve' approach is used by councils and others in the Zero Waste Coordinator networks to inspire and involve communities, households, schools and non-governmental organisations (NGOs) in extending good practice and developing new initiatives for waste reduction and recycling.

Collaborate:

- Partnership approach
- Commitment to incorporate community viewpoints to the maximum extent possible
- Commitment to identify where and how community viewpoints have been incorporated, and to clearly explain reasons when community preferences not incorporated
- Requires a long-term commitment to building relationships and regular meetings
- Builds a strong sense of community ownership
- Provides a good platform to generate new ideas and build capacities and alliances to help find solutions to other council issues
- Requires approachable 'experts on tap' for any workshop or hui
- Can be resource-intensive and costly in the planning and in resources needed to sustain on-going conversations
- May require strong independent facilitation to manage historical or single-issue interest group dynamics or strongly expressed viewpoints.

Examples: Workshops or hui that are open to the community and are not designed to promote a predetermined course of action or limited options. The case-study that CIBR undertook in Kaikōura (Langer et al., 2013) used a 'collaborate' approach to build a science, Iwi and local council partnership, as well as involving wider community.

Empower:

- Involves a complete transfer of the decision-making power to the community, which may not be legally permitted in biowaste management contexts
- Not usually appropriate for decisions that include complex technical considerations, taking responsibility for large financial investments with long-term consequences and managing public health and environmental risks
- Time-consuming and requires significant resources to design and deliver well.

Examples: No examples exist in New Zealand to date. However, the RMA provides the ability to delegate authority to Māori. For example, the ability for consent authorities to transfer responsibilities to Iwi authorities (section 33); the ability for Iwi authorities to become heritage protection authorities and issue heritage orders (section 188); regional policy statements and plans and district plans which take into account any relevant planning document recognised by an Iwi authority and lodged with the council (sections 61(2A), 66(2A) and 74(2A)); and joint management agreements between councils and Iwi (section 32B).

Appendix 2: Sample workshop run sheet

Location: (Give clear instructions so people can find your meeting, or attach a map)

Date/time:

Workshop run sheet

Ground rules:

- Keep an open mind about the issues and options
- Respect each other's views
- Focus on the issues not the personalities
- Maintain confidentiality where necessary
- Seek consensus for decision-making where possible
- Accept the majority view as the Focus Group view where consensus is not available.

Aims:

- Selection criteria – QBL environmental, social, cultural and economic (What matters most?)
- Begin to explore the best options
- Outcome: Council has a list of options for costing and further technical review.

Outline:

7pm	Introductions	Mayor
7.15pm		Selection criteria – environmental social, cultural, economic (Small group work)
8pm		Ranking the QBL criteria
8.10pm		Exploring the options (small group work)
8.45pm		Feedback Where to next?
9pm	Finish	

Detailed run sheet: (preparation and instructions for staff and facilitators only)

Preparation:

Please can we have 'café style' room layout for the day – preferably round tables with chairs 3-4 people per table, 5 small tables, 1 rectangular or square table to side or back of room.

Materials/check list:

	Persons Responsible	Check
Room set up in café style – check with venue for set up. Café style' room layout for the day – preferably round tables with chairs 3-4 people per table, 5 small tables, 1 rectangular or square table to side or back of room.		
Drink and biscuits table – water jug, cups, teabags, hot water urn, coffee, sugar, biscuits etc. Mints for tables?		
Check with venue, Blu-tack on walls? No white table cloths?		
Name tags?		
Map of area (similar to Slide 51)		
Laptop		
Slide projector?		
Large table and/or wall to cluster & put posters on?		
Giant post-it note pad (is expensive with adhesive strip backing, could use flip chart paper and Blu-tack)		
Sheets/small roll of butcher paper (cheaper for cluster exercise, but we can join giant post-it notes together)		
Fine/medium tip different coloured marker pens (check no white table cloths)		
Multi coloured 8cm square post-it notes (x4 packs) Blu-tack, cellotape, Biro pens, scissors Coloured dots (red, blue/green, yellow, silver) Need 4 different coloured packs)		
Blu-tack, cellotape – can bring this		
A4 Questions for exploring options		
A4 Evaluation		
A4 Parking		
A4 Thoughts		

Detailed Run sheet – draft only

Have a plan like this, but be flexible. You might only get through some of the exercises.

Time	Activity	People/materials
6.15pm	Check/set up room.	Facilitator/all to set up tables/materials Parking and Thoughts sheets
6.45pm	Karakia for food Meet & greet.	Tea & biscuits (continuous)
7pm (10 mins)	Karakia – Iwi/mana whenua Mayor - introduction, endorse purpose Council staff – introduce outline process.	Check protocol and order with rūnanga/kaumātua
7.10pm (5 mins)	Facilitator (introduce her/himself, outline aims, expectations, structure of the workshop/hui). Incorporating community values into technical decision-making. First exercise on identifying the environmental, social, cultural and economic criteria that matter most. Acknowledge options that have been submitted and we will get to these later. If not completed please do so in next 5 mins and give to staff member to collate. Whilst we do this, engineer/staff person is going to work on inputting the options you have suggested. He will report to us at 8pm to show the top 5-6. We can then focus on these 'top' options in more detail in the second half of the meeting. Also, whilst we are working, the council staff might try to cluster these (cut and group same options together, 1s first, then 2s, 3s).	How will we weight these to show most popular? 1= 2= 3= 4= 5= 6= 7= etc.
7.15pm	Small group work (4 -5 tables, 4-5 people at each table). Allocate each table – 'Social', 'Cultural', 'Environmental', 'Economic'. Make sure you are with the topic that you really want to contribute to. We need all four areas covered so we have a deeper understanding of each area so this	Facilitator (small groups) - 2 giant post-it note sheets per table - 2-3 Marker pens - ½ cube small coloured post-it notes - Biro's

<p>(5mins)</p>	<p>information can help inform and guide further conversations.</p> <p>Quick intro name and organisation. Check who is sitting at the table beside you – do you need to move? Is there a good range of interests? Do you already know most of these people? Who is missing?</p> <p>Nominate a time keeper who can signal or say if someone is talking too much, give another person a turn, and help keep a process where we go around the table to give each person a turn to share their ideas.</p> <p>Nominate a scribe, someone who is a good open listener and who likes to write things down, but make sure scribe gets their own ideas down too.</p>	
<p>7.20pm (20-30mins)</p>	<p><i>Understanding what matters most</i> Social, Cultural, Environmental, Economic</p> <p>Brainstorm – we want a list of bullet points to consider, have a deeper understanding of what criteria are most important to consider when thinking about wastewater treatment options.</p> <p>Unpack this, what do we mean by QBL etc. values. When we talk about culture, environment in relation to wastewater treatment and discharge, what are the criteria or concerns that underpin our views?</p> <p>What are our key concerns, values, or objectives? What really matters most? These might be impacts.</p> <p>Then, think about how you might measure each criterion, and/or what needs to be done to achieve or uphold this value.</p> <p>Note any questions you might have, or knowledge gaps that you can identify. Questions for experts? Questions? Parked questions?</p> <p>Time permitting: Rotate the posters to a different group to help appreciate there is more than just their value. Move poster to tables.</p>	<p>Facilitator</p>
<p>7.45pm</p>	<p><i>Prioritise (All group)</i></p>	<p>Facilitator</p>

<p>(10-15mins)</p>	<p>Collect all the posters and Blu-tack to wall, or arrange on one big table.</p> <ul style="list-style-type: none"> - Pass around the dots each invited person or interest group, if more than one, talk to each other to decide where to put the 3 dots (green or blue) - And 2 big red dots. Each person to take 3 red dots. - Optional: We could ask elected members and staff to use different coloured dots (yellow or orange) and do this exercise too, but we only count community votes. <p>Keep the dot box secure with a staff member (don't just leave it on a table) as some people may help themselves to extra dots.</p> <p>Get people to walk around the posters. Look at the all issues that others in the room have identified.</p> <ol style="list-style-type: none"> 1. Vote for the <u>three</u> issues that are most important. On Balance, across all the four areas, which three values/criteria matter most for you (blue/green) 2. Vote for the <u>two</u> issues that you think would really get in the way of an option, deal breakers. (red dots) <p>Any crucial issues or criteria missing – write on post-it note and place on poster. Any thoughts on a poster that your group didn't work on.</p> <p>Questions, knowledge gaps?</p> <p>Any thoughts? Surprises? Is this what you expected? Is this how you'd expect the wider community to view things? Why/why not?</p>	<p>Coloured dots</p> <p>Three dots per person (blue, green)</p> <p>Two dots (red)</p> <p>Use dots and mini post-it notes to add comments to posters that you haven't been involved in.</p>
<p>8pm (5-10mins)</p>	<p><i>Options</i></p> <p>Engineer/staff member report on most frequently ranked options.</p> <p>Show how clusters emerging on large table. Have map on standby, link options clusters with areas on map if possible.</p>	<p>Facilitator</p> <p>Data projector</p>
<p>8.05pm</p>	<p><i>Options exercise</i></p> <p>Back into small groups/tables – (Mix it up, sit at a different table, but think about good spread, range of viewpoints). Agree on a scribes and timekeeper roles.</p>	<p>Make an A4 question guide for here. Then they can work on giant post-it notes.</p>

<p>(20-25 mins)</p>	<p>Agreement on taking top five and not all of them. Would then randomly allocate option to each of the five tables.</p> <p>Maybe on table where not your top option, how does it sit. If you don't like, think about why?</p> <p>Title: A sentence to describe this option. Then thinking about the social, cultural, environmental, economic work that you've done, how does the option you are looking at fit with these criteria.</p> <p>List the benefits for this option? List the disadvantages of this option? Try to think about what others might think, think about options and issues/ideas outside your historic thinking, what would wider community think?</p> <p>Questions/prompts: Who is impacted? - Who will benefit? Who might be adversely affected? Who needs to be involved? Who do you need to work with to make this option viable? Bigger picture, wider impacts? What is needed to make this option work? What conditions need to exist for this option to be successful? Who has the power to block or undo this option? What are the uncertainties, unknowns, and knowledge gaps? Questions for experts?</p>	
<p>8.35pm (5-10mins)</p>	<p><i>Big group</i> One person from each group to report to whole room. 1min each to summarise their option and key discussion points. Knowledge gaps perhaps.</p>	<p>Facilitator (all group)</p>
<p>8.45pm (5-10mins)</p>	<p><i>All group</i> Stand around / have a look at the table of clusters. Talk to person beside you. Any surprises? Any underlying issues or tensions between the options? Where are the most unknowns or uncertainties?</p> <p>Has our best option changed? Are there any other options, other than the top five we have worked on today, that you'd like the council to consider?</p>	<p>Facilitator (all group)</p>

	Which options would you like the council to do a full costing and technical review? All five or less?	
8.50pm (5mins)	Thank you to everyone. Anything you want to be heard within this process that you haven't had an opportunity to share, please write down on post-it note and stick to the 'Thoughts' poster. Evaluation forms – optional, to fill out before you go (A4 – What worked well, What could be improved? Any other comments?)	Facilitator (all group)
8.55pm (5 mins)	Council staff - What next? Timeline, feedback, notes of this meeting, next meeting etc.	Council staff
9am (5mins)	Close meeting Mayor – Closing Karakia	Mayor/Iwi
9.10pm	Tidy up and team debrief	Cellotape all the post-it notes to the posters. Label and keep each tables work together.

FROM TAPU TO NOA – MĀORI CULTURAL VIEWS ON HUMAN BIOWASTE MANAGEMENT

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Abstract:

Tapu (forbidden or restricted) and noa (ordinary or free from restriction) are key Māori cultural concepts that continue to influence and inform present Māori praxis and thinking on all aspects of society, including biowaste management. Traditional management of human waste effluent was highly prescriptive. Processes and procedures were nested within cultural values and ethics that in turn were influenced by local context and circumstance. The tapu and noa constructs work in conjunction with other values to govern human behaviour and relationships with the environment at any point in time. However, tapu and noa are not fixed and can change through time as a result of a specific action or consequence; thus influencing the ability to interact or use an object or resource which create interesting management implications for human waste. This paper will discuss these factors, based on literature and previous research with Ngāi Tahu (Pauling & Ataria 2010) and hapū from the Taupō/Rotorua districts and suggest how these constructs might guide local practice and inform management frameworks for biowaste reuse.

Introduction

Tapu and noa are fundamental traditional constructs in Māori philosophy and spirituality that once governed the societal infrastructure and continue to have application and influence in contemporary Māori society. These terms are generally well known amongst New Zealanders, but there is a limited awareness of the extent to which the customs surrounding tapu and noa affected traditional Māori life and a general lack of appreciation and deeper understanding of how these concepts continue to guide Māori thinking, process and practice today (Mead 2003).

A concise definition of these concepts is difficult because; a) there are obvious difficulties in maintaining the integrity and meaning of complex philosophies and concepts when translating across cultural boundaries; b) there are a broad range of meanings and interpretations of tapu and noa that are dependent on the context in which they are being used, and the relationship with other traditional frameworks; c) Māori culture has spatial and place-based nuances – locally based

knowledge rather than national uniformity; and d) the manifestation of cultural concepts today is affected by multiple societal influences and experiences.

However, the following generic explanations provide a useful starting point for discussion.

Understanding Tapu and Noa

Tapu is a term that is often used to convey the meaning 'sacred'. However, the words 'prohibited', 'forbidden', 'special', 'not ordinary' and 'to be set apart' convey a broader definition that encompasses the attributes of tapu (Mead 2003). All things are considered to possess tapu.

Early ethnographers and academics wrote extensively on tapu – albeit their interpretation through a Western cultural lens. Like many first principles in the Māori cultural values system, there is the conviction that tapu is descended from the realm of the Atua (deity) and therefore tapu encompasses all of the extraordinary powers to create and influence inherent to them (Barlow, 1991; Shirres 1982). This deeply religious connotation coupled with an unyielding commitment to and belief in the power of that spirituality is why tapu was such a powerful instrument in traditional society (Harrison in Benton et al., 2013:410) and continues today. This acknowledgement of tapu as being derived from the Atua meant that any deliberate neglect of the 'laws of tapu', even accidental or brought about by the act of another person, incites the anger of the deity, resulting in consequences to the transgressor and/or their kin group (Shortland, 1882) at the hands of the gods or otherwise at the hands of members of the tribe. A breach of 'tapu' was tantamount to committing a hara (violation) and carried with it severe penalties – including death, as was the case with the French explorer Marion du Fresne who fished in an area regarded as tapu (Kelly, 1951).

A pragmatic assessment of tapu was offered by Waddy in his Master of Law thesis in 1927 (in Benton et al., 2013:415) who said:

“Compared with some of our modern practices – legal, social and hygienic – it seems to have been constructed upon the keystone of common sense and expediency... there was always good reason underlying the tapu.”

Tapu can exist for a period of time, for example a rāhui (closure or ban) to temporarily restrict the people associating with a natural resource, e.g., a beach or collecting kai moana (sea food) from a specific area or location. This might be in respect of a recent accident or drowning, or to help manage overfishing or seasonal pressures on a resource. In this example, tapu provides a means of control over an activity or resource and can be understood as quite a practical and prescriptive response that can respectfully address spiritual dimensions in grieving or bereavement, and in practically managing scarce or fluctuating resources to protect environmental and human health.

Tapu can have temporal and fluxing dimensions, whereby time and timing are important determinants in governing or signalling a transition to unrestricted practice. Therefore, this also positions tapu as a transitional concept in supporting ritual and practice to help mediate between the unseen and spiritual world of Atua and the practical world of people and their relationships to the material environment.

Tapu can also have an intrinsic or material quality expressed as a more permanent exercise of tikanga or protocol. For example, a burial ground is always tapu and there is always a strict protocol for behaviour whereby eating is forbidden, and washing hands on exit from an urupā (cemetery) is required. A geyser for example, may be deemed in a more permanent state of tapu, with the effect of protecting human health and exposure to an unpredictable geological hazard of scalding mud or explosive water.

Despite the obvious pragmatic aspects tapu also exists as a spiritual power with mysterious and unknown dimensions, including the uncertainties, chance and complex causative relationships invoked within complex metaphysical domains. Notions of consequence, retribution and discretionary capacities for forgiveness may exist as aspects of these spiritual dimensions.

Shirres (1996) refers to the “extension of tapu” which is a consequence of all things possessing tapu, but that tapu is not equal in all things. This implies that the tapu of separate objects does not exist in isolation, and more importantly different aspects or levels of tapu will interact with each other resulting in outcomes that are either constructive or destructive in nature. Recognising this, Māori established a series of controls and processes that were often very prescriptive and designed for the sole purpose of achieving specific desired outcomes and avoiding what were often drastic consequences. Tapu provides something of a conduit for the material world to exercise some control and protection in managing intrinsic and unknown qualities, and complex interactions. The processes for deliberately making people or objects noa are an example of this.

Noa is the antithesis of tapu, describing the state of a place, resource or activity that is deemed ordinary or safe, and not subject to control. It is a stative verb and adverb denoting ‘freedom from restriction’ or ‘uncertainty’, ‘indefiniteness’, ‘randomness’ (Benton et al., 2013:266). That something deemed ‘ordinary and safe’ is also bestowed with ‘randomness’ and ‘uncertainty’ seems contradictory, hinting perhaps at the flux and tension between tapu and noa as permeable and entwined. This definition of noa makes clear the inescapable power of tapu as an ever-present intrinsic state. Similarly the strength of tapu as a practical material mechanism to control the randomness and uncertainty that is within noa, and the realities of living with chance, change and low level risk in everyday life.

Tapu and noa are specific cultural understandings built upon complex and intricate understandings of, and interrelated relationships between, people, flora, fauna, whenua and the wider spiritual and metaphysical environment. Other foundational concepts of Māoridom – such as mana, utu, mauri, whakapapa and manaaki inform the expression and understanding of tapu and noa under different contexts. The balancing and appraising of tapu and noa in relation to these important multifaceted concepts helps inform tikanga as protocol that guides appropriate or best practice (Figure 1). The complexity in understanding tapu and noa as inter-relational concepts strengthens our key message of the need for guidance from local mana whenua in determining the appropriate interpretation and application of these concepts.

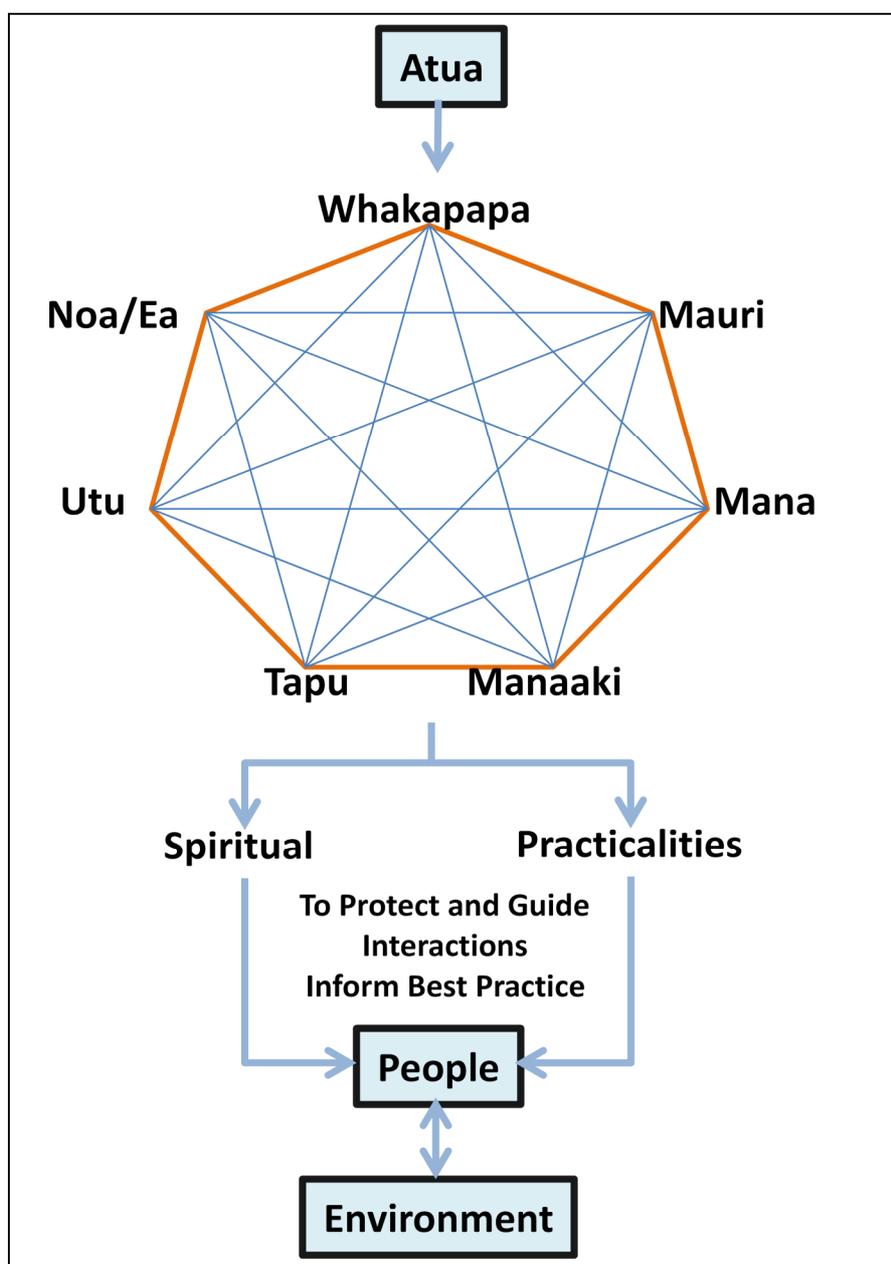


Figure 1. The inter-related values framework showing the complex interactions of Māori fundamental cultural concepts and how they manifest as a guide to inform best practice interactions between people-people and people-environment.

Tapu, Noa and Human Biowastes

The relationship of human biowaste, or biosolids, and the environment has traditionally been viewed by Māori through this inter-related values framework described above. The rationale for use of karakia and other customs associated with the separation of various types of human waste in the living arrangements of a traditional Maori village was passed from one generation to the next through archetypal stories of prominent ancestors such Hema, Tawhaki, Rata and Hina (Hineteiwaiwa). These ancestors feature in the tribal lore of many areas regarding the disposal of faeces (Hema), construction of paepae-hamuti or toilet facilities (Tawhaki), the use of toilet waste for certain ritual purposes (Rata) and protocols for handling menstrual fluids (Hina). These traditional narratives about other ancestors like Tamaiwaho, who helped bring knowledge of healing and medicinal plants to the world, also highlight the potential consequences for human health and wellbeing if tikanga is not followed when managing the various types of human waste.

Throughout the traditional discourse on waste management tapu has been a principal value that has informed and underpinned well-established Māori behaviour and practice. Shirres' (1996) commentary on tapu provides a helpful framework to derive one view about how tapu relates to this waste stream.

All humans possess tapu, the prestige/power that is inherited from the Atua, and are therefore very tapu. This spiritual tapu logically extends to human body parts and waste products that are produced and excreted by humans that are, by association, also very tapu. This elevated tapu state demands that prescriptive procedures and processes are implemented to avoid instances of extension/consequence where the tapu associated with biosolids creates a destructive outcome when it interacts with tapu from another entity/thing. Therefore, rituals and practices were established to mediate between the spiritual dimensions (world of the Atua) and the practical world of people and their relationships to the material environment for positive outcomes: protection of human and environmental tapu.

Traditionally human waste management practice was heavily influenced by local environment. Whilst there was variability across regions, Iwi and hapū, some generic practices have been cited and drawn from interviews.

Spatial separation and designation of areas specifically for waste (e.g., human waste like faeces, urine and menstrual waste etc. and other activities like bathing, food waste etc.) from significant places (e.g., food growing and harvesting, food preparation and the collection of drinking water), activities and people was key. Traditionally this has been done by the separation of toilet and kitchen or living zones within a marae settlement, being mindful of land slope and run off in locating latrines, or by demarcating different zones for bathing, kaimoana, water collection along a

river to minimise the effects within a catchment area. There have also typically been specific practices for dealing with death and illness that are based on separation as a means of control.

The notion of tapu and noa as being transitory, introduces the prospect that things deemed tapu could potentially change their spiritual state over time – assuming that the requirements of time, a detailed knowledge of the composition of the waste stream and the appropriate cultural and management process have all been satisfied. Although arguably not as mainstream as separation, there are some accounts of latrine sites, over time, becoming sites for productive gardens, or where human waste is applied to areas later used to grow kai. However, whether this was intentional change of land use for productive crop growth, or reflected a change in ownership is not clear in all cases.

Contemporary Expression and Manifestation of Tapu and Noa

Today there are different forces or trajectories that influence how tapu or noa, and other traditional cultural values, may be expressed in response to issue like biosolids management (Figure 2). The erosion of traditional constructs is widespread, resulting from the systematic undermining of Māori culture from multiple sources. The impacts of colonisation have marginalised Māori participation in decision-making relating to natural resource management processes – although this is changing rapidly with Treaty-based legislation and the changing power dynamics following Treaty settlement. Furthermore, it is highly likely that the place base; community demographic (rural or urban); the strength of traditional knowledge and power base; and the evolution of governance structures and resources following Treaty settlements are all factors that may influence the strength and range of views on the transition of tapu to noa and the exercise of cultural management frameworks for many natural resource issues. As such local government needs to be cognisant of these factors in determining appropriate modes of engagement with Māori.

Modern reticulated sewage and wastewater treatment also raise entirely new challenges of scale and the ability to exercise traditional controls of tapu and noa. Designed to facilitate effective and timely removal of hazardous waste away from built up areas, these systems commit communities to a specific model of treatment reliant on existing infrastructure. While these systems are effective, management of them could be improved to meet cultural concerns. For example, hospital, mortuary and menstrual waste (spiritual tapu associated with body parts or bodily functions) are substances entering the wastewater system that present considerable cultural challenges for some hapū in being assured that the municipal treatment processes can adequately perform a transition from tapu to noa. Discussion around these aspects will often highlight differences and tensions in traditional Māori values and Pakeha concepts of treatment and purity.

It is also important to contrast the key differences between traditional waste (including human waste) and contemporary waste streams when considering the application of tapu and noa to biosolid waste. The most striking differentiation relates to a clear knowledge of what constitutes the waste stream – and more importantly the ability to control what is put into this waste stream, i.e. maintain separation. Traditional Māori waste management processes ensured a high level of compliance around what was disposed of and when, thus creating confidence and commitment. For example there was an implicit knowledge of the constituent composition of waste streams to ensure inappropriate mixing and appropriate disposal processes were adhered to, e.g., middens, wood waste from carvings and menstrual waste. This is impossible to achieve with modern reticulated systems that process wastes from multiple sources. There is less ability to control and be certain of what goes into the system, treatment processes, more diverse cultural practices, increased volumes and an ability to transport waste to other locations. Another factor is the aging waste infrastructure whose capacity to deal with peak loads and maintain clear separation between different waste sources (stormwater, sewage and tradewastes) is questionable. A further distinction between traditional and contemporary waste streams lies in the prevalence and proliferation of chemicals that are in use in contemporary society. In a passage from a Ngā Kaihautū Tikanga Taiao (Māori Advisory Committee to the Board of the Environmental Protection Authority) report to an application under section 28 of the Hazardous Substances and New Organisms Act (1996) to import baits containing difethialone¹ the issue of tapu and noa is discussed in relation to chemical persistence:

“Many Māori consider that within the realms of Papatūānuku and Ranginui there exist a range of established processes and relationships that continuously cycle chemicals through the spiritual states of tapu (restricted state) and noa (relaxed or normalised state). In a scientific context these processes could be termed bio- and physico-chemical transformation which acts to breakdown and modify chemical compounds to basic building blocks for other uses or re-partitioning back into the environment. Compounds that have been synthesised with properties that convey resistance to these natural processes are often met with opposition – particularly if their intended use involves direct deployment into the environment or at some point during the life cycle of these products environmental exposure occurs.” (Ngā Kaihautū Tikanga Taiao, 2012).

¹ A hazardous substance that was proposed to be used as a vertebrate toxic agent.

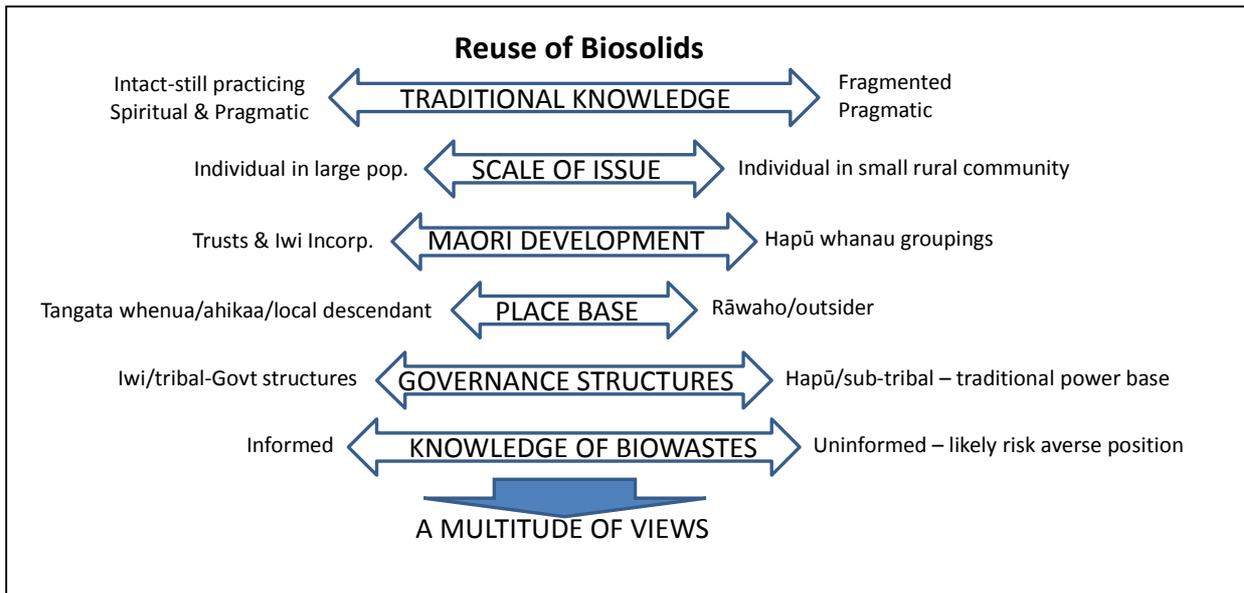


Figure 2. Contemporary influences and realities that inform the expression of Māori culture and practice.

Co-management to Reflect Traditional and Contemporary Insights

These contemporary realities were expressed in interviews with Māori business owners, kuia and kaumātua undertaken in previous research. These revealed that:

- Māori have a range of views about land application and beneficial reuse of wastewater and biosolids.
- Overall there was a strong sense of ownership of the problem and a view that good waste management was an integral part of exercising kaitiakitanga or stewardship of the environment.
- There are varying degrees of cultural/spiritual knowledge, but many are cautious about beneficial reuse within the food chain. Human health was mentioned as a concern, especially with new chemicals and pharmaceuticals. Some expressed ‘not feeling comfortable’ as a way of articulating how use in the food chain sat uneasily within the frameworks of cultural knowledge and practice. There are also concerns about mortuary and hospital waste, and some would be more open to beneficial reuse options if local government could divert these wastes. Menstrual waste was also a concern for some, but this input was recognised as more difficult to control in contemporary society. Keeping human waste and run off away from sacred places such as the urupā had continued importance. Some mentioned saying a quiet karakia in performing rituals at the urupā, for burying afterbirth, or in disposing of waste on the marae.

- There was a healthy tension and active reflection between traditional ‘separation’ of human waste from food, and being pragmatic and ‘moving with the times’. Some talked of ‘longdrop’ sites ‘being covered up and don’t go near it’ and ‘not used for anything else’ for 20 plus years. Others shared historical examples of gooseberry bushes for eating being grown on old latrine sites, and a koromiko tree planted on a re-dug latrine site with the leaves used for rongoa to cure stomach cramps. In more contemporary practice some spoke of Uncles that grew beautiful sweet potatoes, but not telling the Aunties that they were being grown in biosolids from the municipal plant.
- Small communities, marae and land trusts were interested in better utilisation of contaminated sites and in exploring how they could manage multiple waste streams (including septic tank waste) on site.
- Māori productive sector businesses, for example, were willing to explore biosolids reuse as ‘hypothetical’ in future planning for sustainable on-site waste management systems, but they were also concerned about how beneficial reuse might impact on export markets, branding and commercial sensitivities around their food production.
- Proximity was important and there was a localised aspect in thinking about waste and reuse. For example, people would consider reuse and be more inclined to eat foods grown in their own waste from a composting toilet, rather than municipal-scale waste.
- There were concerns about the unknown and knowledge gaps: ‘What is in it?’ was always the foremost question when the CIBR scientists asked communities about how they might consider pollutants vs. nutrients, and the risks and benefits of reuse.
- Protection of water was a common theme, with land application mostly being preferred as a first option.
- Methods of treatment that employed natural processes like composting and vermicomposting (earthworms) were considered favourably, but concerns remain about the ability of these techniques to treat chemical contaminants (recalcitrant and new and emerging contaminants) and what were appropriate reuse options for the composted product.

Iwi, land trustees, hapū and Māori business owners tend to be very keen to engage with local government on waste and biowaste management issues and reinforces our research data showing that Iwi do not adopt a ‘flush and forget’ approach that can be typical of ratepayer responses to this issue.

Overall there was a great deal of openness and willingness to carefully consider and weigh up options. Many valued the opportunity to access new scientific information and have constructive conversations about what tapu and noa mean, and importantly how these can inform contemporary practice.

Conclusion

Traditionally the ability for Māori to exercise local control over the separation and disposal of different biowastes was much easier. Today it is far more difficult to control what goes into the wastewater system and where it is treated and disposed of – especially where households are connected to a reticulated system. This is due to legislative and policy requirements and the complex ethnic composition of New Zealand communities. There is also greater scientific awareness of, and ability to study, complex mixtures of contaminants, such as household pharmaceuticals and emerging contaminants from industry or new consumer product ingredients for personal care and hygiene. Influencing household consumption or behaviours (and/or the formulation of consumer products) to reduce or eliminate the disposal of chemicals of this nature is a key challenge. Likewise an aim of diverting trade, hospital or mortuary biowaste may present interesting challenges and infrastructure costs for local government and rate payers.

Tapu and noa are Māori cultural concepts that operate alongside other concepts and values to inform traditional knowledge and resource management frameworks. There is a breadth of cultural knowledge on the topic of biowaste, biosolids and wastewater management, a willingness and openness to explore new forms of co-management, and an expectation of being involved in decision making. Where this is the case Māori view biowastes and biosolids as something that should be owned and responsibly managed, rather than forgotten about or left to the environment to cope with.

Biowaste management in New Zealand requires more sophisticated forms of governance, as well as genuine conversations about the limits of our knowledge, what ought to be the limits of our treatment, and how we can best continue to manage human impacts upon the environment.

It is a good time for local government to become more informed and have some meaningful conversations with Iwi, rūnanga and local Māori land owners about long-term planning and co-management of the environment, water and biowaste. How well local government embraces this will directly correlate to the degree that the Māori world view is incorporated into decision-making.

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GLOSSARY

Agricultural land: Horticultural, cropping and pastoral land.

Agronomic rate: The agronomic rate for biosolids application is designed to provide the amount of nutrients needed by a crop or vegetation to attain a defined yield, while minimising the amount of nitrogen that will pass below the root zone of the crop or vegetation to the groundwater.

AOX: the abbreviation of the sum parameter for water soluble "adsorbable organic halogens" in which 'A' stands for adsorbable, 'O' for organic and 'X' for the halogens chlorine, bromine and iodine. Most AOXs do not have a specific use and are not intentionally manufactured but are by-products.

Beneficial: In the context of organic material applied to productive land, the product must improve soil physical, chemical or biological health.

Beneficial reuse: when a material destined for landfill is captured and made into a high-value material or product that will feed into, or benefit, another system or product. For example, transforming food waste into compost, or soil conditioner that will be used to improve the health of the soil to grow food or plant life that will be beneficial to the community or environment.

Bio-availability: The availability of substances for uptake by plant and animal species.

Biosolid: A sewage or sewage sludge derived from a sewage treatment plant that has been treated and/or stabilised to the extent that it is able to be safely and beneficially applied to land. Biosolid is a Biowaste Product that contains waste material of human origin.

Bulk use: Application of organic waste material to land equalling or exceeding 50 m³ by volume per application.

Composting: A product manufacturing process that biologically stabilises organic materials. It is ordinarily an aerobic process taking place at thermophilic temperatures (about 55°C) because of heat released by biochemical transformations.

Contaminant: Any substance (including heavy metals, organic compounds and micro-organisms) that, either by itself or in combination with other substances, when discharged onto or into land or water, changes or is likely to change the physical, chemical or biological condition of that land or water.

Contaminant concentration limits: The maximum permissible amount of a given contaminant in organic materials or derived products (see **Error! Reference source not found.** of this Guide).

Degraded Land: Land where there is a decrease in the optimum functioning of soil in ecosystems.

DEHP: the most common member of the class of phthalates which are used as plasticizers.

Discharger of organic waste products: The party responsible for applying biosolids, manures or derived products to land; the discharge consent holder.

DS: Dry solids.

EMS: Environmental management system.

Grazed land: Land that is being grazed or will be grazed in the next 12 months. Grazed land may have a cover of pasture or fodder crops.

Groundwater: Sub-surface water from which wells or springs are fed; strictly, the term applies only to water below the water table.

Heat drying: A manufacturing process whereby sludges or slurries are dried by direct or indirect contact with hot gases to reduce the moisture content typically to 10% or lower.

Helminth: Parasitic worm-like invertebrate.

Horticultural land: Land used for process food crops, leaf crops, root crops.

LAS: linear alkylbenzene sulfonates and commonly used in cleaning agents.

Lime stabilisation: A manufacturing process involving the addition of sufficient lime or lime mixtures to raise the pH of the material to 12 after 2 hours of contact.

Manure: organic matter, mostly derived from animal faeces

Maturation: The conversion and amendment of the rapidly biodegradable components in the organic material (e.g. sludges and manures) to substances similar to soil humus that slowly decompose. Compost that is insufficiently mature will reheat and generate odours in storage and upon rewetting. It may also inhibit seed germination by generating organic acids and inhibit plant growth by removing nitrogen as it decomposes in the soil.

Most probable number (MPN): A sample analysed by dispersion in an extracting solution, by excessive dilution, and then using statistical analysis based on the positive or negative growth for each sample.

NP/NPE: nonylphenols and nonylphenoethoxylates are surfactants.

Nuisance: Something which is noxious, dangerous or offensive.

Organic product: A good quality product manufactured from a mixture of natural organic material.

Pastoral land: Grazed land, including land used for dairy, beef, sheep and deer production.

Pathogens: Disease-causing micro-organisms such as certain bacteria, viruses and parasites.

PFOA: Perfluorooctanoic acid is a synthetic surfactant and commonly used in the emulsion polymerization of fluoropolymers.

PFOS: Perfluorooctanesulfonic acid is another fluorosurfactant and commonly used in stain repellents.

PFU: Plaque-forming unit.

pH: A measure of the hydrogen ion concentration in a solution. On the pH scale of 0–14, a value of 7 represents a neutral condition; decreasing values (below 7) indicate increasing hydrogen ion concentration (acidity); increasing values, above 7, indicate decreasing hydrogen ion concentration (alkalinity).

Phyto-availability: The availability of substances (e.g., metals, nutrients) for plant uptake.

Phyto-toxic effects: Adverse toxic effects of contaminants on plant growth and development.

Producer of organic products: A person or organisation that either produces organic material by operating a product manufacturing facility (e.g., a composting, heat-drying, lime stabilisation or digestion plant) or who manufactures a blended product from organic materials.

Protozoa: Small, single-celled animals including amoebae, ciliates and flagellates.

Resource Recovery: is the selective extraction of disposed materials for a specific next use, such as recycling, composting or energy generation in order to extract the maximum benefits from products, delay the consumption of virgin resources, and reduce the amount of waste generated.

Sensitive sites: Sites at which organic material should not be applied due to the ecological, social or cultural values associated with them.

Sewage sludge: The unstabilised organic solid material settled out from domestic and industrial wastewater during the treatment process. It contains pathogens, organic material, nutrients, metals and other chemicals from residential (human waste) and commercial properties, and tradewaste discharges. Sewage sludge is an unavoidable product of wastewater treatment. Untreated sewage sludge would not meet the stabilisation and/or contaminant grades defined in this Guide and cannot be beneficially used without further treatment and stabilisation.

SOUR: Standard oxygen uptake rate.

Urban land: Domestic gardens, lawns, public parks and gardens, golf courses, sports fields, turf farming, land rehabilitation.

VAR: Vector attraction reduction (see below).

Vectors: Organisms such as rodents and insects that are attracted to putrescible organic matter and that may spread disease by carrying and transferring pathogens.

Vector attraction reduction: Processes by which organic material is treated to remove or reduce substances that attract vectors.

Verified: Independently checked or audited.

Vermicompost: Mixture of vermicast and partially unprocessed organic matter.

Vermicomposting: The use of earthworms to convert organic waste into fertilizer.

Vermicast: (also called worm castings, worm humus or worm manure) Solid organic product resulting from the transformation of compostable organic materials in a controlled vermiculture process, which complies with the characteristics of Table 3.1, NZS4454:2005

Wahi tapu: Maori sacred site.

Waste: an unwanted or undesired material or substance left over or used inefficiently from a manufacturing process (industrial, commercial, or agricultural operations,) or from commercial activities.

Worm Tea: (or compost tea) is a liquid fertiliser made by steeping finished compost in water.

WSP: Waste stabilisation pond.

WWTP: Wastewater treatment plant.

water

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