Guidelines for Beneficial Use of Organic Materials on Productive Land

Centre for Integrated Biowaste Research

Ministry for the Environment
Manatū Mō Te Taiao

MINISTRY OF HEALTH
MANATŪ HAUORA

Ministry for Primary Industries
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wasteMINZ

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Volume Two

TECHNICAL MANUAL

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The Steering Group worked on the principle of consensus decision-making. Consensus was reached on the majority of issues. Steering Group members contributed to decision-making within their areas of expertise and provided an industry or sector view according to their experience. They were not necessarily representing the entire sector group from which they were selected.

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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 Table1-2 below.

Table 1-2 Product Pathogen Standards

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

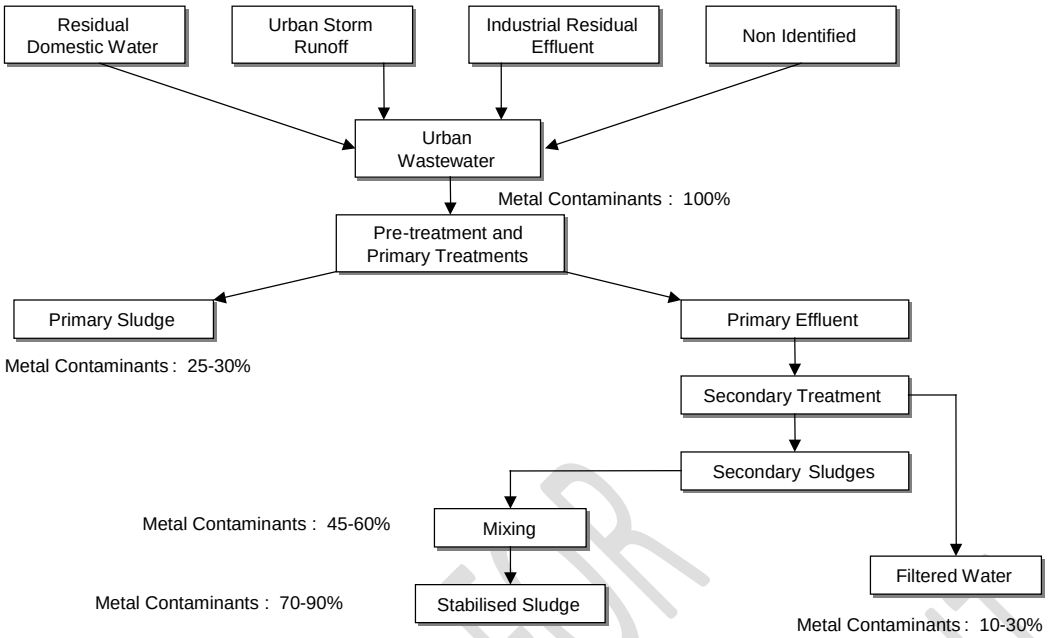


Figure 2-1 Origin and fate of metals during treatment of wastewater

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

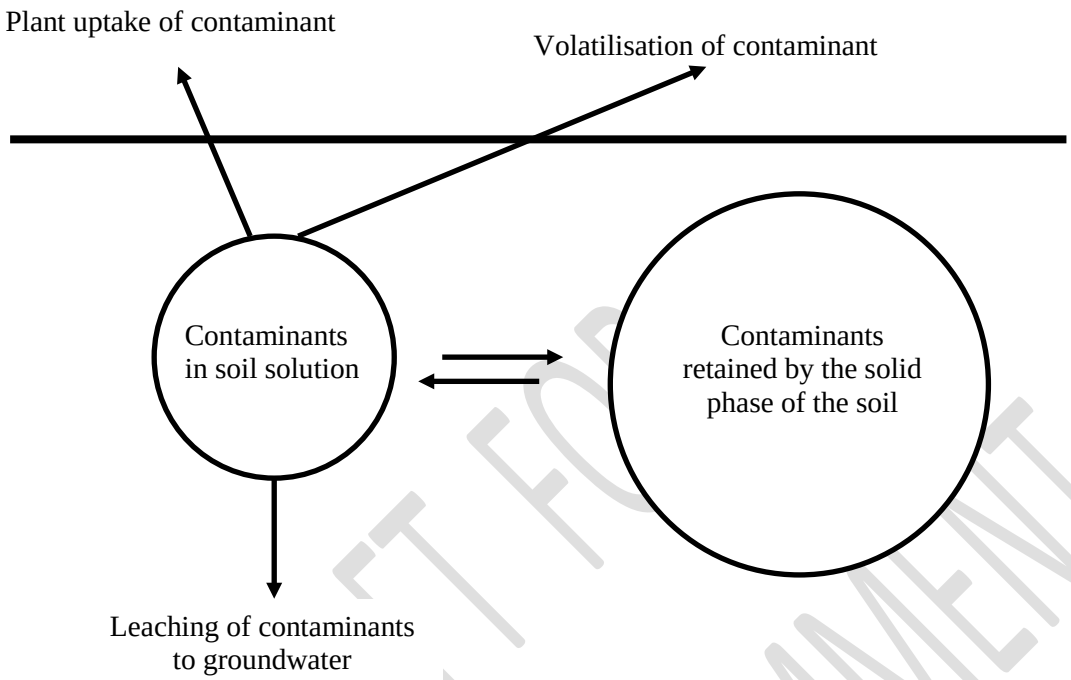
2.3.1 INTRODUCTION

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 alumino-silicate 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 dimethlyarsine 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 decrees. The sorption of those metals that occur in anionic forms decrees 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.

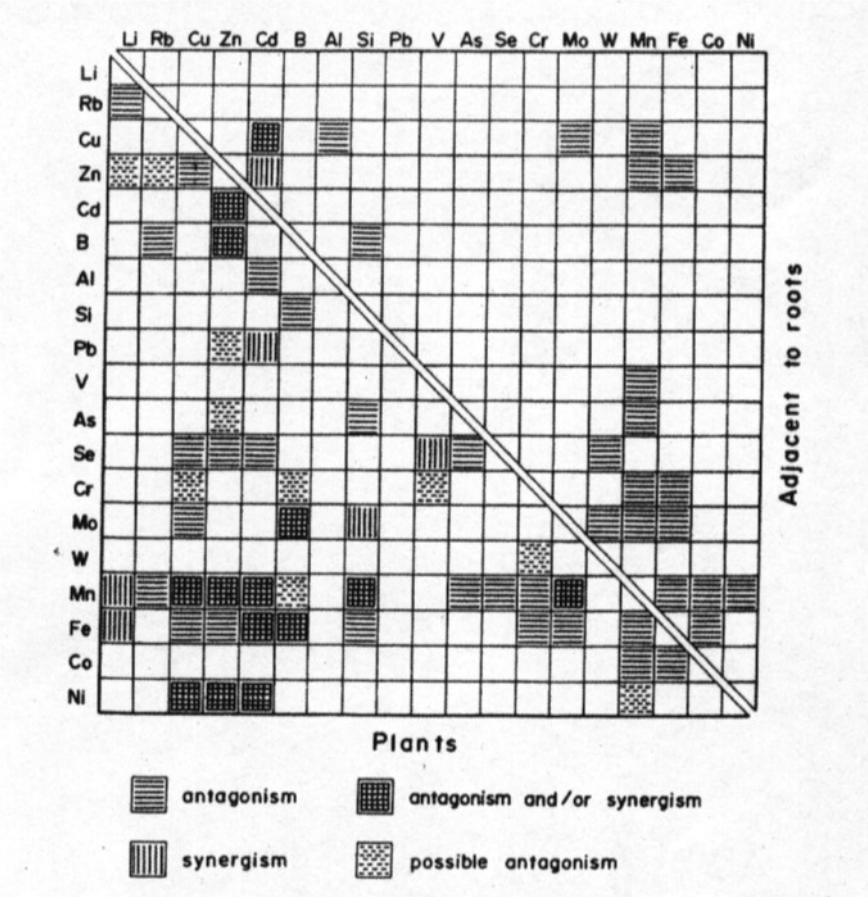
Apart from field study data, knowledge of metal movement through soils is based primarily on studies using homogenised, repacked soil columns (Camobreco et al., 1996). Such studies, even when using coarse-textured soils, have tended to support the contention that cationic trace meals are basically immobile (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 Burridge, 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 2-3Table 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*** at least one VAR/odour method from the list below: 1. mass of volatile solids in biosolids shall be reduced by a minimum of 38%[c]; or 2. biosolids ≥ 90% DS if heat dried at T > 80 °C; or 3. T ≥ 40°C for ≥ 14 days and T_{ave} ≥ 45°C; or 4. SOUR @ 20°C ≤ 1.5 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.
	1. Time–temperature process **a) ≥ 7% DS** Within the relationship $t = \frac{131{,}700{,}000}{10^{0.14T}}$; t = days, T = °C, where T ≥ 50°C and t ≥ 15 seconds, or **b) < 7% DS** Within the relationship $t = \frac{50{,}070{,}000}{10^{0.14T}}$; t = days, T = °C, where T ≥ 50°C and t ≥ 30 minutes, or	
	c) Composting[a] (i) In-vessel: T ≥ 55°C for ≥ 3 days, or (ii) Windrow: T ≥ 55°C for ≥ 15 days with a minimum of 5 turnings during this period.[b]	
	2. High pH – high temperature process pH > 12 (measured at 25°C) for ≥ 72 hours, and maintain T > 52°C for 12 consecutive hours within the 72 hours, all from the same chemical application and drying to > 50% DS afterwards.	
	3. Other processes Demonstration by agreed comprehensive process and product monitoring that the Grade A pathogen levels can be consistently met.	
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≥ 55°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), NRMMC (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 standards[1]

Pathogen	Verification sampling	Routine sampling
E. coli	< 100 MPN[2]/g	< 100 MPN/g
Campylobacter	< 1/25 g	N/A4
Salmonella	< 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 NRMMC (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.

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[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), NRMMC (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 chips[3]. 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 (≈35°C) mode or a combination thermophilic (> 50°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 recommend 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	▪ Mass of volatile solids in biosolids shall be reduced by a minimum of 38%; or ▪ SOUR @ 20°C ≤ 1.5 g/m^3 for liquid sludges from aerobic processes; or ▪ pH ≥ 12 @ 25°C for at least 2 hours and pH ≥ 11.5 for 22 more hours.	May be applied immediately ***plus*** soil incorporation ***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).
	▪ Storage/restricted access	Store or lagoon for at least 1 year prior to application ***plus*** soil incorporation ***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).
Public amenities, sport fields, public parks, golf courses, play grounds, land reclamation	▪ Mass of volatile solids in biosolids shall be reduced by a minimum of 38%; or ▪ SOUR @ 20°C ≤ 1.5 g/m^3 for liquid sludges from aerobic processes; or ▪ pH ≥ 12 @ 25°C for at least 2 hours and pH ≥ 11.5 for 22 more hours.	Store or lagoon for at least 6 months prior to application ***plus*** soil incorporation (***plus*** restriction on public access for period of time necessary to establish a full vegetation cover on the land.
	▪ Storage/restricted access	Store or lagoon for at least 1 year prior to application ***plus*** soil incorporation ***plus*** restriction on public access for a period of time necessary to establish a full vegetation cover on the land.
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.	▪ Mass of volatile solids in biosolids shall be reduced by a minimum of 38%; or ▪ SOUR @ 20°C ≤ 1.5 g/m^3 for liquid sludges from aerobic processes; or ▪ pH ≥ 12 @ 25°C for at least 2 hours and pH ≥ 11.5 for 22 more hours.	May be applied immediately ***plus*** soil incorporation ***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.

Land use	VAR requirement	Recommended controls
	▪ Storage/restricted access	Store or lagoon for at least 1 year prior to application ***plus*** soil incorporation ***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.
Forest, trees or bush scrubland	▪ Mass of volatile solids in biosolids shall be reduced by a minimum of 38%; or ▪ SOUR @ 20°C ≤ 1.5 g/m^3 for liquid sludges from aerobic processes; or ▪ pH ≥ 12 @ 25°C for at least 2 hours and pH ≥ 11.5 for 22 more hours.	May be applied immediately ***plus*** public access restricted for 6 months ***plus*** buffer zones should be fenced and signposted.
	▪ Storage/restricted access	Store or lagoon for at least 1 year prior to application ***plus*** public access restricted for 6 months ***plus*** buffer zones should be fenced and signposted.

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 NRMMC 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.	▪ *E. coli* ▪ *Salmonella* ▪ *Campylobacter* ▪ enteric viruses ▪ helminth ova ▪ VAR
	Routine sampling	≥ 1 grab sample per week	▪ *E. coli* ▪ VAR
B	Product verification[2]	Not applicable for pathogen testing	▪ VAR[3]
	Routine sampling	Not applicable for pathogen testing	▪ VAR[3]

[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]	▪ Metals: 1 composite[2]/week over a 3-month period ▪ Organics: 1 composite sample[2]/month over a 3-month period ▪ Dioxins: 1 composite[3]/3 months
	Routine sampling[1]	▪ Metals: ≥ 1 composite[2]/2 weeks ▪ Organics: 1 composite[2]/2 months ▪ Dioxins: 1 composite/year[4]

[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: ▪ 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 0ºC and 4ºC. 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 1991[6]

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.

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[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. Polices 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 Sheet[8] (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?”

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.

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.

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.

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 m^3 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 nonylphenolethoxylates 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
NEW ZEALAND
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