Alternative Waste Treatment - Mixed Waste Derived Organics

Technical Advisory Committee report to

the NSW Environment Protection Authority

Report – April 2018*

Contents

The EPA has prepared the Technical Advisory Committee report for public release. As part of the publication process company names and locations have been de-identified, personal information removed, terminology and acronyms through the report have been checked for consistency and clarity, and background context on the purpose of the report has been prepared.

* This report should have been dated - 24 May 2018 (final report)

Overview

The EPA has prepared the TAC's report for public release. As part of the publication process company names and locations have been de-identified, personal information removed, terminology and acronyms through the report have been checked for consistency and clarity, and background context on the purpose of the report has been prepared.
Mixed Waste Organic Outputs (MWOO) is an organic rich material predominantly made from the organics in general household (red lid bin) waste and produced at Alternative Waste Treatment (AWT) facilities.

In March 2010, the then Department of Environment, Climate Change and Water (DECCW), which was the predecessor organisation of the NSW Environment Protection Authority (EPA)) granted, "The organic outputs derived from mixed waste exemption 2010" (the 2010 Exemption). This 2010 Exemption allowed for the land application of MWOO under certain conditions. However there was a lack of data available at the time to adequately inform the development of those conditions. Consequently, DECCW committed to conduct research to fill some of the knowledge gaps, explain scientific uncertainties and identify emerging issues associated with the land application of MWOO and its potential impact on human health and the environment.

Following the introduction of these requirements in 2010, a multi-year, multi-study independent research program was commissioned by the NSW EPA. The projects were designed to generate a data set relevant to local soil and conditions in NSW that would inform a review of the EPA's regulatory requirements. That research concluded in August 2017 and has been independently peer reviewed by renowned scientists.

The panel process

In September 2017, to demonstrate transparency and establish an arm's length decision process, the EPA formed an independent Technical Advisory Committee (TAC) under section 29 of the *Protection of the Environment Administration Act 1991*. The purpose of the TAC was to assess the findings of all projects conducted as part of the EPA's research program and provide recommendations to the EPA regarding how the research should be used to improve policy and regulation relating to the land application of this waste. The TAC comprised of scientific experts in environmental chemistry and toxicology, soil science, agriculture, human health risk, environmental exposures, policy development and stakeholder interactions.

The TAC met in the NSW EPA offices at 59 Goulburn St, Sydney as follows

1) 22nd September 2017
2) 6th November 2017 (teleconference)
3) 13th December 2017
4) 1st February 2018

This document provides a report of the TAC's deliberations and the recommendations to NSW EPA in relation to the research undertaken and how this may be used to inform and improve policies and regulations applicable to this waste stream.

Site visit

A field visit was conducted to a facility on 22nd September 2017. In general, it was a well-run complex. Separation of waste at the beginning of the process looked appropriate. However, the waste stream going into compost beds/homogenisation processes included a high proportion of visible waste materials including nappies, plastics, clothing etc. The final MWOO material contained visible signs of plastics of multiple colour and fragments of glass (Figure 1).

Figure 1. Image of MWOO from Facility A where the cut-out displays extent of visible plastics (white, red and purple fragments) for an approximate 30x60 cm surface area.

Executive Summary

- An Alternative Waste Treatment Technical Advisory Committee (TAC) was formed by NSW EPA in 2017 to:
    - assess the research findings from all projects and sub-projects conducted as part of the NSW EPA's Alternative Waste Treatment (AWT) research program; and
    - provide recommendations to the EPA regarding how the research should be used to improve policy and regulation relating to the land application of this mixed waste organic output (MWOO).
- The TAC met 4 times (3 face-to-face meetings) and reviewed the reports to summarise the findings and produce the recommendations outlined below.
- It is clear the current use of MWOO on broadacre agricultural land, with application rate restricted to 10 t/ha, could not be classified as beneficial reuse in terms of improved crop production or beneficial effects on soil chemical or physical quality. Higher, and/or repeat, application rates are needed for the material to have any significant effects on crop growth and quality, and on soil chemical and physical quality.
- It is also clear that higher application rates run the risk of greater contamination of soils by metals, persistent organic chemicals, and physical contaminants. Under the NSW EPA draft internal policy for beneficial re-use or recovered waste materials provided to the TAC,

no net accumulation of contaminants is stated as a goal. The current use of MWOO would not conform to this draft policy goal.

- Land application of MWOO in agriculture is currently undertaken where no information on the quality of the receiving soils is known. This leads to a risk of increased concentrations of persistent contaminants in the environment, which may limit land use options, and present additional risks if land use changes.
- Risks due to the use of MWOO to rehabilitate minesites was not a focus of the NSW EPA research program. In most cases, minesites generally have soils that have elevated metal concentrations, often low pH and low levels of organic matter. The risk pathways for human or ecological exposure at rehabilitated minesites will be very different to agricultural land - MWOO could provide significant benefits and fewer risks in these situations. However, depending on final land use, and depending on NSW EPA policy on retaining multifunctionality of land in perpetuity (e.g. rehabilitated mined land could become agricultural land in the future), risks may need to be assessed using a default agricultural land use scenario.
- The risk assessment for chemical contaminants in MWOO raises concerns regarding the effects of several contaminants for broadacre agriculture. Some of these (cadmium, copper and zinc) can be managed using current and proposed frameworks/guidelines for biosolids by applying approaches outlined in the National Environment Protection (Assessment of Site Contamination) Measure. However, for other contaminants (polybrominated diphenyl ethers (PBDEs), phenol and phthalates) significant concern for human and environmental health remain and suitable control measures are needed.
- The presence of physical contaminants in MWOO also raises significant concerns in terms of human and animal health (glass contamination of crops and forage), as well as concerns for aesthetic quality of soils and soil physical quality degradation (plastics).
- Glass, PBDEs and metals are persistent in soils. Persistence is one of the key attributes of any contaminant that raises concerns about its potential impact on environmental or human health (along with bioaccumulation and toxicity).

- Little data were available to perform a robust risk assessment for pathogens in MWOO. Risks appear low, but insufficient sampling/analysis and routine monitoring has been undertaken to allay concern.

Recommendations

Management

1) In their current form, MWOO generated under the AWT program is not suitable for use on broadacre agricultural soils. The use of MWOO in horticultural soils is also not recommended.

2) Better source separation is needed to remove plastics, metals and glass contaminants at the householder level if MWOO is to be applied to land.

3) Better engineering/technology is needed to reduce sources of metals/plastics/glass during processing of waste if MWOO is to be applied to land.

4) It is recommended that the current criteria for the physical contaminants be reviewed and stricter controls implemented. An unknown proportion of material is visible and potentially adds more contaminant to the land over time, with comminution of plastics in particular raising concerns for soil physical quality. A volumetric-based limit for plastics would be more appropriate rather than a gravimetric-based limit, given their very low density.

5) If MWOO is to be applied to agricultural land, it is recommended that mechanical breakdown of waste through processes such as hammer-milling and crushing not be used to meet physical contaminant limits, as already specified in the resource recovery orders for composts and pasteurised garden organics. The breakdown of plastics to smaller particles should not be considered beneficial, as colloidal particles (<2 µm) have been demonstrated to cause pore blockage in soils, resulting in significant reductions in ability to allow water infiltration. A limit for physical contaminants having a diameter < 2 mm should be set.

6) If MWOO is to be applied to agricultural land, it is recommended that the application rate guidance be reviewed and harmonised with other waste orders/guidelines (e.g. biosolids) using new frameworks as described in the National Environmental Protection Measure, Contaminated Sites (2013 Amendment). The major chemical contaminants of concern are PBDEs, phenol, phthalates, cadmium, copper and zinc. As soil pH has a large effect on the bioavailability of potentially toxic metals, minimum soil pH limits are also essential if MWOO is applied to land.

7) If the practice of land application of MWOO is to continue, some registration scheme and knowledge of pre-existing soil quality is required. This includes information and registration of the quality and concentrations of contaminants of the MWOO for each application site.

Research

8) If MWOO is to be applied to agricultural land, long-term trials are needed to evaluate contaminant attenuation and toxicity to soil flora and fauna. Before new requirements are formulated, the concerns with respect to contamination with heavy metals and organic contaminants, particularly with respect to a wider range of soil types and the issues relating to what is defined as "long term", must be addressed.

9) If MWOO is to be applied to agricultural land, the risk pathways of leaching and runoff to water supplies needs to be reviewed and more field-relevant research undertaken to evaluate the risks, particularly for mobile chemicals (e.g. PFAS) and where high application rates are allowed (minesites).

10) Effects of physical contaminants on soil porosity and water movement are needed, especially for colloidal size physical contaminants < 2 µm diameter.

11) The presence of plastic particles in MWOO needs greater characterisation in terms of their physical properties such as particle size distribution, their chemical composition - particularly heavy metals, and the subsequent release of heavy metals from microplastic particles in a range of representative soils. Also, the separation of primary and secondary microplastics in the <2 µm fraction would give some indication of the relative contribution of the sources of both primary and secondary plastic particles to MWOO.

12) Further characterisation and composition of MWOO (including temporal changes) may be required to identify pathogens that may be of concern to human health, including a literature review to identify pathogens of concern.

13) The TAC recommends a quantitative microbiological risk assessment be undertaken looking at all exposure pathways to characterise the risks to humans. The risk assessment should provide guidance on reference pathogen testing, frequency, sampling regimen and criteria limits for risk management.

1. Beneficial re-use

1.1. Context

Australia's National Waste Policy outlines Australia's waste management and resource recovery direction to 2020. The aims of the National Waste Policy are to:

- avoid the generation of waste, reduce the amount of waste (including hazardous waste) for disposal;
- manage waste as a resource;
- ensure that waste treatment, disposal, recovery and re-use is undertaken in a safe, scientific and environmentally sound manner; and
- contribute to the reduction in greenhouse gas emissions, energy conservation and production, water efficiency and the productivity of the land.

The Draft NSW Waste Avoidance and Resource Recovery Strategy 2013-2021 aims to reduce the environmental impact of waste while using waste resources more efficiently. This will entail avoiding and reducing waste generation, increasing recycling, diverting more waste from landfill, managing problem wastes better, reducing litter and illegal dumping.

Recycling waste materials to land is one option to reduce waste streams entering landfills, as many wastes may contain valuable nutrients and carbon (in the form of organic matter) which can improve soil chemical and physical properties, leading to improved crop and/or animal production on that land. However, waste re-use on land may pose risks to the environment and to human health, which must be controlled through source controls, processing technologies or restrictions on use. A key principle underlying the recycling of waste to land is that the re-use is *beneficial* i.e. improves soil chemical, biological or physical properties leading to greater growth of terrestrial plants and animals.

In Victoria *beneficial re-use* has been defined in the Environment Protection (Industrial Waste Resource) Regulations 2009 (as amended in 2016) more generally as "a substitute for an input or raw material in a commercial, industrial, trade or laboratory activity where the substitute (a) has one or more similar hazard properties to the input or raw material; and (b) would not require any environmental risk management controls other than the controls required for the input or raw material (Vic EPA 2016).

The Environment Protection and Heritage Council (EPHC) produced guidance in 2003 for assessing the beneficial re-use of industrial residues on land (EPHC 2006). While these guidelines do not specifically include municipal mixed organic wastes, the same guiding principles are useful to consider.

- The application of industrial residues to land is in accordance with the principles of Ecologically Sustainable Development;
- the re-use and recycling of industrial residues are consistent with the concepts of the Waste Management Hierarchy (i.e. waste avoidance, reduction, re-use, recycling, treatment and disposal);
- The re-use and recycling of industrial residues to land occur only if they are beneficial and do not cause harm to the environment, human health or agriculture;
- State and territory agencies integrate into existing policy and regulatory frameworks the

guidance provided by the criteria and general information of this document to ensure a consistent and common approach in determining "if industrial residues are fit for re-use to land"; and

- The re-use and recycling of industrial residues only proceed with the involvement of stakeholders, and through the provision of information and transparency in decision – making as stated in the Council of Australian Government's (COAG) Principles and Guidelines for National Standard Setting and Regulatory Action.

NSW EPA provided the TAC with a draft internal policy on beneficial re-use which states that "To be considered beneficial, the properties of a waste derived fertilizer or soil amendment must be comparable to a commercially available fertilizer or soil amendment" and that "The NSW EPA's policy includes a requirement that waste to land activities cause no net accumulation and irreversible/long term adverse effects on the environment."

For re-use of MWOO on land, it is therefore important first to consider the evidence that the land application of the material is *beneficial*. Consideration then needs to be given to the potential adverse effects of MWOO application to land in terms of soil quality, plant and food quality, ecological health and human health. It is against this context that the use of MWOO was assessed given the results of the NSW EPA research program.

2. Beneficial effects of MWOO on soil physical properties

2.1. General background

The function of soil-plant systems is completely reliant on air and water infiltration, water retention and plant access to this water. Water infiltration facilitates nutrient movement into the soil system to meet the demands of such production systems. Air movement is essential as roots and soil organisms respire oxygen. MWOO could improve soil physical properties through the addition of organic matter to soil.

2.2. Improvements in soil physical condition due to addition of organic matter

The NSW EPA research program did not extensively examine the effect of MWOO on soil physical properties, with the emphasis being more on soil chemical properties. Data for the effect of MWOO in improving soil physical condition are derived from Project 2 (Whatmuff et al. 2017) and Project 4 (Wilson et al. 2014).

In pot trials (Project 4), there was no effect of MWOO on soil bulk density at application rates up to 140 t/ha equivalent (Wilson et al. 2014). In field runoff experiments, there was no effect of MWOO on water infiltration rates or runoff volumes at rates of application up to 100 t/ha – higher rates decreased soil runoff (i.e. increased infiltration). Plant available water (the amount of water in soil between field capacity and permanent wilting point) was increased by applications of MWOO as was air-filled porosity, but only by rates of 100 t/ha or greater (Whatmuff et al. 2017). Although water retention curves for amended soils showed that addition of the MWOO increased the water holding capacity in these soils, increases in plant available water were not significant and were further compromised by increased salinity levels in the field soils. Given that total organic carbon (TOC) concentrations in the amended soils dropped by up to 30 % for the incorporated MWOO treatments, and by up to 50% in the surface applied MWOO treatments, it is likely that the measured improvements in soil physical fertility may not persist.

There was a statistically significant decrease in soil bulk density, but only for high rates of application of MWOO (100 t/ha and higher). The decreases in soil bulk density presented above were mirrored by increases in soil porosity. Soil porosity increased above levels in the control soil, but again, only for the highest rates of MWOO application (5% for 100 t/ha, and 7% for 200 t/ha). Hence, in broadacre agricultural use with total application rate limited to 10 t/ha, MWOO would not have a beneficial effect on soil physical properties – much higher application rates, either singly or cumulative and continuing, would be needed to demonstrate a beneficial effect. However, this increases the risk of detrimental effects from physical and chemical contaminants (discussed further below).

No data were available to directly assess the effects of MWOO on soil hydraulic conductivity saturated or unsaturated), air permeability, aggregate stability, surface crusting, or clay dispersion.

3. Beneficial effects of MWOO on soil chemical properties

The literature review of Wilson et al. (2014) and the experimental programs described in Wilson et al. (2015) and Whatmuff et al. (2017) provide evidence for beneficial effects of MWOO on soil chemical properties. Effects of MWOO on soil chemical properties will be a function of the cumulative rate of MWOO applied to land, coupled with the concentrations of nutrients in the waste, and waste pH. Concentrations of nutrients and contaminants in MWOO in comparison to other materials are shown in Table 1.

Table 1. Concentrations of nutrients and contaminants (mg/kg) in MWOO in comparison to other wastes.

	Facility A	Facility A	Facility B	Facility B	Composted green waste	Composted biosolids	Chicken manure
	Project 2	*Project 3*	*Project 2*	*Project 3*	*Project 2*	*Project 2*	*Project 2*
Aluminium	17,000	5,539	13,000	6,681	12,000	19,000	13,000
Arsenic	6	5	ND	7	10	5	ND
Boron	32	21	26	18	29	18	33
Cadmium	2	2	4	2	1	0	ND
Chromium	82	52	100	36	61	130	23
Cobalt	6	5	8	4	5	7	7
Copper	260	716	380	154	67	110	120
Iron	14,000	7,519	16,000	12,702	12,000	26,000	9,100
Lead	220	268	280	150	66	48	5
Manganese	350	255	440	323	320	290	850
Mercury	NT	0	NT	0	NT	NT	NT
Molybdenum	3	6	5	9	2	2	10
Nickel	41	117	40	24	12	23	14
Selenium	NT	ND	NT	ND	NT	NT	NT
Sulfur	4,500	3,108	2,800	3,589	2,600	2,500	6,600
Zinc	700	645	600	487	240	220	570
Calcium	34,000	27,422	26,000	29,297	19,000	13,000	5,000
Magnesium	3,100	1,997	2,100	2,702	3,800	4,200	9,000
Potassium	10,000	5,558	6,800	7,841	1,000	6,200	24,000
Sodium	6,800	6,552	6,700	5,327	1,800	1,600	5,600
Nitrogen	21,000	14,846	13,000	18,523	16,000	8,300	31,000
Phosphorus	5,900	3,969	3,600	5,246	3,300	7,400	19,000
EC (dS/m)	7.60	8.43	4.60	8.45	1.0	1.3	8.1
pH	8.30	6.54	8.70	6.88	8.6	7.5	8.5
Organic carbon ( )	24	34	18	33	24	12	24
DEHP	302	178	292	70	NT	NT	NT

- All units are mg/kg unless otherwise specified.

While Table 1 provides a single snapshot of the quality of MWOO in relation to other wastes, it does not capture the highly heterogeneous nature of the material and the changes in composition that can occur over time. Ranges of nutrient and contaminant concentrations can be very large, with high concentrations in various contaminants regularly occurring due to changes in the source materials. Later in this report, this highly heterogeneous nature is explored further.

Concentrations of organic carbon (OC) in MWOO are high – ranging from 18-34% and similar or higher than those in other land-applied wastes. Concentrations of the major plant nutrients, nitrogen (N), phosphorus (P) and potassium (K) are in the same range or slightly lower than those in other organic materials applied to land – green waste compost, chicken manure, composted biosolids and biosolids. Concentrations of calcium (Ca) are higher and magnesium (Mg) similar to other solid wastes used on land. Concentrations of sulphur (S) are lower than those in biosolids, but similar to those in other wastes. The pH values of MWOO are neutral or alkaline, while electrical conductivities (EC) are high in comparison to other land-applied wastes.

In the literature review of Wilson et al. (2014) (Framework Report), the value of MWOO-derived OC addition to soils was noted, as this will increase the cation-exchange capacity (CEC) of light textured and/or low-OC soils. Indeed, Wilson et al. (2015) observed this experimentally in the laboratory experiments (Project 4) where MWOO was added to ten soils from NSW. The pH of acidic soils was also increased by MWOO and this would contribute to increases in soil CEC (in addition to the CEC derived from OC in the MWOO). However, statistically significant increases were only evident at application rates > 40 t/ha. Similar results were observed by Whatmuff et al. (2017) in the field trials (Project 2) using this material on moderately NSW acidic soils, although increases in pH and CEC observed initially were less evident after 3 years.

The high salinity of MWOO means that soils have high EC values immediately after incorporation of MWOO (Wilson et al. 2014, 2015, Whatmuff et al. 2017). The high EC of MWOO used in the experiments is perhaps not surprising. The cations most likely to be present in a 1:5 suspension in water are Ca^{2+}, Mg^{2+}, K^+, Na^+, NH_4^+, and possibly Mn^{2+} while the anions would be Cl^-, $SO_4^{=}$, HCO_3^-, $S^{=}$, NO_3^- and anions of low molecular weight organic acids (LMWOAs).

However, this is only a transient effect as the soluble salts are usually leached to deeper soil layers with rainfall (Wilson et al. 2014, Whatmuff et al. 2017).

Concentrations of N, P, K, S and micronutrients in soil are generally raised in soil according to the application rate of MWOO and the concentrations of these elements in the material (Wilson et al. 2014, 2015, Whatmuff et al. 2017).

These increases in concentrations of both macro- and micronutrients in soil will provide useful additions of nutrients to soil and would obviate the need for macronutrient fertilizer application for at least 1-2 years and likely 5-10 years for micronutrients. However, when MWOO is applied at rates of greater than 10-20 tonnes/ha these nutrient additions are large in comparison to crop annual nutrient requirements and nutrient runoff/leaching needs to be considered (Whatmuff et al. 2017).

4. Beneficial effects of MWOO on soil biological properties

In the review of international literature in the Framework Project (Wilson et al. 2014), many researchers have noted beneficial effects of MWOO applications to soils on soil biological activity, due to the addition of C (a source of energy for heterotrophs) and other nutrients (N, P, S, etc.). Again, positive effects are generally related to MWOO application rate although some researchers note negative effects at high rates in the year of application, likely related to high salt (EC) concentrations.

Laboratory experiments examining soil respiration by Wilson et al. (2015) showed increased soil respiration immediately after application, likely due to the addition of OC and nutrients in MWOO. This effect dissipated over time.

Whatmuff et al. (2017) noted that worms avoided MWOO-treated soils immediately after application, but this behaviour was absent once the material had aged for 2 years under field conditions. Thus, the high EC immediately after application likely explained the initial avoidance behaviour. Substrate-induced nitrification (SIN) was also observed to be unaffected with MWOO application rate. Examination of the potential nitrification rate (PNR) indicated that the MWOO reduced the PNR as application rate increased, reducing by 1.6 fold at an application rate of 200 t/ha. Substrate-induced respiration (SIR) was generally unaffected or was increased by MWOO application. Substrate-specific respiration (Microresp™) was also measured by Whatmuff et al. (2017) with the results showing generally positive (beneficial) responses immediately after application and no effect or negative responses (adverse effects) 3 years later.

The CSIRO report (Williams et al. 2017) was focused more on the effects of microplastics on soil biological function, but also had a soil only and MWOO-amended soil treatments, which could be used to assess the effects of MWOO addition. Extensive testing of microbial diversity, gene abundance, substrate-induced respiration, substrate-induced nitrification, nematode mortality and reproduction and earthworm reproduction revealed no significant consistent beneficial effect of MWOO addition (1% w/w addition rate, equivalent to 13 t/ha assuming a bulk density of 1300 mg/m^3 and 10 cm depth of incorporation).

In general, the evidence for beneficial effects of MWOO on soil biological properties was not strong.

5. Beneficial effects of MWOO on yield/quality of agricultural crops

Given the range of plant nutrients in MWOO, it is not surprising that beneficial effects on plant growth have been noted in the literature (Wilson et al. 2014). In the NSW EPA research program, Wilson et al. (2015) observed positive responses in glasshouse experiments using 4 NSW soils (including one minesite soil) at low applications (20-50 t/ha) but no effect or decreases in growth at high application rates. The reason for the lack of response, or negative responses, at high application rates was not investigated but may have been due to high soil EC at high application rates. In field trials, Whatmuff et al. (2017) found few positive yield or dry matter responses in millet (Year 1) from application of MWOO to soil, and where observed, high rates of application were needed (100 t/ha). In years 2 and 3, wheat was grown and positive responses to MWOO application were observed, although again high rates of MWOO application (60 t/ha or higher) were needed to obtain significant differences.

In terms of grain quality, significant increases were observed for protein concentrations in wheat grain by Whatmuff et al. (2017) which is a beneficial effect. However, grain cadmium (Cd) concentrations were also significantly increased after application of MWOO, albeit by a small amount (discussed more below). Grain protein quality will be improved dependent on amounts of native N in the soil, the N content of the MWOO and the MWOO application rate. These effects will be short lasting, as the N added is subject to losses from soil in gaseous emissions and from leaching.

6. Overview of beneficial effects of MWOO on soil quality

It is evident from the research program, particularly Projects 2 and 4 (Whatmuff et al. 2017; Wilson et al. 2015) that high rates of MWOO are needed to have any significant beneficial effect on soil properties or crop yield – from the field trial results (Whatmuff et al. 2017), rates of up to 30-100 t/ha were generally needed to affect crop yield, increases in soil pH, CEC, plant available water, soil porosity and soil nutrient concentrations. Hence, the current practice of limiting application rates in agricultural soils to 10 t/ha could not be regarded as *beneficial re-use*. Increasing rates of application (either single or cumulative) to agricultural soils will raise concerns regarding the adverse effects of contaminants in the material on soil or crop quality.

However, the TAC notes that the research program did not address the evaluation of the beneficial effects of MWOO on minesite soils that are generally high in metal contaminants before amelioration and low or devoid of organic matter or plant nutrients. In addition, many of the key risk pathways that raise concerns for use of the material in agricultural settings e.g. food chain contamination (see below), are absent or minimal in minesites, dependent on final use of the rehabilitated land.

7. Detrimental effects of MWOO on soil quality – chemical contaminants

7.1. Metals and metalloids

Metals, comprising heavy metals, alkali and transition metals, are naturally occurring and vary in concentration in soils depending on regional geology. They are a group of elements characterised by high electrical and thermal conductivity, malleability and the ability to reflect light. Metals of many types are widely used in society. Some metals such as cobalt (Co) (a component of Vitamin B12), manganese, magnesium, copper and zinc are required in small doses to maintain optimal health, other metals, such as aluminium, have no known biological function.

Human activity has had major impacts on the distribution of metals in the environment, with industrial processes such as mining, burning fossil fuels or waste and the manufacture of certain goods releasing metals into the air and ultimately leading to their distribution in the soil and groundwater systems. Their presence in fertilisers has also increased environmental concentrations.

Metals are considered persistent chemicals, which can cycle in the environment, and even if they change in form, they remain in the environment. Metals/metalloids are found in MWOO in varying concentrations due to a mixed waste stream with metals in many types of products including packaging, batteries, wire, from dust in homes, car detailing products, to mention a few. While the AWT separation process attempts to separate cans, batteries, etc. and other large sources of metals for recycling, much is maintained in the system and ultimately found in the waste as evidenced by the reported concentration in the MWOO sampled as part of the EPA research program (Table 1). Metals/metalloids present in the final waste material include arsenic (As), Cd, Co, copper (Cu), chromium (Cr), manganese (Mn), antimony (Sb), selenium (Se), tin (Sn), strontium (Sr), titanium (Ti), thallium (Tl), vanadium (V), and zinc (Zn), but given the nature of the material many more may also be present including the rare elements from vehicle related activities (Lough et al, 2005). The metal concentrations in the material vary depending on the sources in the process at any given time and are quite variable over time (average percentage coefficient of variation = 46, samples from 20/08/2015 to 29/09/2017, data provided by Facility A. Measured metal concentrations in MWOO reported in Project 3 (NSW OEH 2016) are shown in Table 2.

Mean concentrations are lower than the current absolute maximum concentrations specified in the 2014 NSW Resource Recovery Order, however maximum reported concentrations have exceeded the exemption criteria for Cd, Cr, Cu, Ni, Pb and Zn. It is noted there are no environmental threshold criteria specified in the Resource Recovery Order for Ba, Be, Co, Mn, Ag, Sr, Ab, Ti, and V.

The presence of metals in MWOO leads to concerns about the increase in metal concentrations following land application, which may have adverse environmental and human health effects. Metals/metalloids can affect both plant and animal health and reproduction, soil function, and may contaminate the food chain and water supplies.

Table 2. Concentrations (mg/kg) (n=64) Facility A and Facility B (NSW OEH 2016).

Metal	Facility A		Facility B	
	Median	**Range**	**Median**	**Range**
Ag	1.3	<0.52-6.7	0.99	<0.51-2.2
Al	5200	4100-21000	6700	4400-10000
As	4.5	3.0-7.9	6.4	<0.51-2.2
Ba	120	90-230	120	84-620
Be	0.15	<0.1-0.21	0.12	<0.11-0.38
B	22	<11-33	17	<11-36
Cd	2.0	<0.52 – 5.1*	1.20	<0.51-15*
Cr	51	34-160*	27	17-440*
Co	4.4	3.3-51	4.3	7-4.3
Cu	210	89-9100*	160	63-320
Hg	0.26	<0.02-0.53	0.24	0.019-1.3*
Li	2.4	<2.1-3.1	2.6	<2.1-3.1
Mn	240	180-1300	320	200-830
Mo	4.7	2.4-120	2.55	<2.0-110
Ni	25	15-2900*, **	24	12-42
Pb	250	160-1000*,**	130	42-1300*,**
Sb	4.6	<3.1-160	3.95	<3.1-7.7
Sr	85	68-490	78	54-190
Sn	15	7.5-38	21	8.5-1800
V	9.3	6.4-22	12	7.0-19
Zn	480	270 – 5100*	485	280-720*

* Above NSW Resource Recovery Order 2014, maximum allowable waste concentration
** Above Health-Based Investigation Levels (HBILs), Contaminated Sites NEPM (NEPC, 2013a).

Apart from Pb, metal/metalloid concentrations in the MWOO are similar, or in the same range, as those in sewage biosolids, for which detailed risk assessments have been undertaken in Australia (Heemsbergen et al. 2009; Warne et al. 2007) and elsewhere (Chaney 1980).

In terms of food-chain hazards, Chaney (1980) classified metals and metalloids broadly into 4 groups based on their risk pathway (Table 3).

Table 3. Metals/metalloids classified in groups according to potential food-chain risk via plant uptake (adapted from Chaney, 1980).

Group 1	Group 2	Group 3	Group 4
Silver (Ag)	Mercury (Hg)	Boron (B)	Arsenic (As)
Chromium (Cr)	Lead (Pb)	Copper (Cu)	Cadmium (Cd)
Tin (Sn)		Manganese (Mn)	Cobalt (Co)
Titanium (Ti)		Molybdenum (Mo)	Molybdenum (Mo)
Yttrium (Y)		Nickel (Ni)	Selenium (Se)
Zirconium (Zr)		Zinc (Zn)	Thallium (Tl)

Group 1 is comprised of the elements which pose a low risk of food chain contamination because they are not taken up to any extent by plants, owing to their low solubility in soil and, consequently, negligible uptake and translocation by plants. Elevated concentrations of these elements in foods usually indicate direct contamination by soil or dust.

Group 2 includes the elements which are strongly sorbed by soil surfaces, and while plant roots may absorb them, they are not readily translocated to edible tissues, and therefore pose minimal risks to human health. These elements however could pose a risk to grazing animals (or humans) if soil is ingested.

Group 3 is comprised of the elements which are readily taken up by plants, but which are phytotoxic at concentrations that pose little risk to human health. Conceptually, the “soil-plant barrier” protects the food chain from contamination by these elements.

Group 4 consists of elements which are the highest risk for food- chain contamination as they pose human or animal health risks at plant tissue concentrations that are not generally phytotoxic. Chaney originally classified As in Group 2, but research over the last 20 years has indicated that flooded rice systems are at risk from As transfer through the food chain due to low redox conditions in flooded soils increasing the solubility of As for uptake by rice – hence As should now be classified as a Group 4 element i.e. high risk. The concentrations of As, Co, Mo, Se and Tl are low in MWOO and not at levels that pose considerable risk to the food chain.

Concentrations of Cd in MWOO are similar to those in biosolids and are high enough to cause concerns for food chain contamination, and therefore controls on inputs or soil concentrations are needed.

As well as evaluating risks due to Cd in biosolids, the National Biosolid Research Program (NBRP), established and managed by CSIRO (McLaughlin et al. 2007), evaluated the potential ecological risk from metals in biosolids. A preliminary risk ranking was undertaken for metals and metalloids in relation to the existing ecological investigation levels at that time – Cu and Zn were identified as the highest risk metals due to possible adverse effects on plants and soil organisms, and hence, along with Cd, were the focus of the NBRP research program. Project 3 also identified Cu and Zn as priority metal contaminants that could potentially pose environmental risks after application of MWOO to land (NSW OEH 2016). In addition, Project 3 identified Al and Mn as metals of concern but given background concentrations in soils and the environmental criteria used to assess the risk from these metals, the TAC views these metals as being of low risk (discussed further below).

The NBRP developed a set of maximum permitted concentrations (MPCs) for Cd, Cu and Zn in soil to protect the food chain (using wheat as the indicator crop) and to protect soil function. These MPCs took into account the bioavailability of the metals once added to soils and the bioavailability of the metal in the biosolids (McLaughlin et al. 2006; Heemsbergen et al. 2009) with MPCs varying according to soil pH (Cd, Cu, Zn), organic matter content (Cu) or cation-exchange capacity (Zn). The 2013 revision of the National Environmental Protection Measure, Contaminated Sites adopted a similar approach and methodology (NEPC, 2013b) to produce ecological investigation levels for Cu, Ni and Zn taking soil bioavailability into account (NEPC, 2013c). Similar approaches have been adopted in Europe for risk assessment of metals (Smolders et al. 2009).

MWOO sampled as part of the EPA research programs has Cu and Zn concentrations similar to biosolids, so risk from these metals in MWOO would be better managed through a similar approach to those used for biosolids, as recommended by the NBRP. As soil pH has a large effect on the bioavailability of Cd, Cu and Zn, limits on soil pH are essential if MWOO is applied to land. Furthermore, given NBRP findings, the maximum permitted soil concentrations as specified in the 2014 Resource Recovery Exemption would not be protective for all soils – low clay and organic matter soils would be at risk from plant phytotoxicity and microbial toxicity of Cu and Zn, respectively, and exceedances of the Food Standards Australia New Zealand (FSANZ) food Cd standard would be likely for wheat (and other more sensitive crops such as potatoes, leafy vegetables, etc.). The NBRP undertook a national series of multi-year trials examining the soil-plant transfer of soluble Cd and biosolid Cd in Australian conditions (McLaughlin et al. 2006) and identified that wheat grain Cd concentrations could exceed the maximum level (ML) set by FSANZ in soils having total Cd concentrations less than 1 mg/kg. The outcomes from the program suggested graded Cd limits based on soil pH, or a lower soil Cd limit given minimum pH criteria. Wheat is also not the highest risk crop in relation to crop Cd accumulation – horticultural crops are often higher risk (e.g. leafy vegetables, tuber and root crops, etc.). The use of MWOO in horticultural soils is therefore high risk for Cd through the food chain pathway (as well as for issues related to pathogens and physical contaminants, discussed below).

Lead concentrations are high in MWOO sampled as part of the EPA research program, with maximum values exceeding those specified as permissible in the NSW Resource Recovery Order and exceeding HBILs specified in the NEPM Contaminated Sites (NEPC 2013a). Lead reacts strongly with soil components to form insoluble precipitates or is strongly bound to soil mineral and organic matter, so risks to plants, soil organisms and the food chain is smaller than for Cd. Plants also do not readily absorb Pb or translocate it to food organs. The main issue related to Pb contamination in agricultural soils is through animal ingestion of Pb or Pb contamination of harvested crops through dust adherence (McLaughlin et al. 1999). This could be a potential risk pathway where MWOO is surface applied and not incorporated into soil.

7.2. Persistent organics and emerging contaminants

The volume of organic chemicals in use is higher every year and increasingly products in households contain or emit persistent organic chemicals that end up in waste and landfill. Plastics in common use have increased the presence of PBDE flame retardants (used in electronics, coatings and a range of products); phthalates; bisphenol A, triclosan, poly- and perfluorinated alkyl substances (PFAS) etc. These chemicals are so-called emerging chemicals of concern and a number of them are listed under the Stockholm Convention. In addition, the breakdown products are also increasingly being found in the environment, leading to other sources of exposure. Past use of pesticides and herbicides also present on-going risks in products and soils. There are an increasing number of toxicological studies reporting potential health effects arising from these contaminants.

A systematic evaluation of the occurrence of organics in MWOO was conducted during 2008-2010 with high concentrations reported (Project 3) and a conclusion that PBDEs, phenolics, phthalates, polyaromatic hydrocarbons (PAHs), organotin and the pyrethroid pesticides were priorities. Table 4 outlines the range of organics tested and the concentration ranges.

Table 4. Organic contaminant analysis in MWOO (mg/kg) (NSW OEH 2016) and NSW EPA 2018 sampling and analysis.

Compound	Facility A	Facility B
Phenol	4.8-85	<0.42-98
Phthalates	0.48-2,600	<029-180
Chlorobenzenes	Below LOD	Below LOD
Nitrobenzenes	Below LOD	Below LOD
Pesticides	Few detected, very low	Few detected, very low
Herbicides	Few detected, very low	Few detected, very low
PCBs	Below LOD	Below LOD
Bisphenol A	14-27	4-100
Tributyltin (TBT)	<0.0005 – 0.058	<0.0005-0.0011
PBDEs Total	3.8-720	0.096-0.970

7.3. Brominated flame retardants

Brominated flame-retardants have been included in foams, plastics and textiles since the 1970's principally to prevent fires. There are many types of brominated flame-retardants including PBDEs, Polybrominated biphenyls (PBB), brominated cyclohyrocarbons, hexabromocyclododecane (HBCD) and tetrabromobisphenol A (TBBPA). PBDEs have been associated with neurotoxic health effects in both animal and human studies (Costa and Giordano, 2007, Fonnum and Mariussen, 2009). They are also considered endocrine disruptors (Chao et al. 2007, Main et al. 2007, Meeker et al. 2009). PBDEs are persistent in the environment and hence humans continue to be exposed, even after manufacture has ceased. PBDEs have been identified in dust in Australia with elevated concentrations found in house dust (Stasinska et al.
2013). Dust has previously been reported as an important exposure pathway. PBDEs presents a risk to the environment and health due to their persistence in soils that have MWOO applied.

PBDEs were identified in MWOO at concentrations up to 720 mg/kg. The risk assessment conducted by NSW OEH (Project 3) identified high concentrations of PBDEs occurring in MWOO that could be of concern for human health. As with other organics and metals, the long-term effects of these compounds are not clear.

7.4. Phenolics

Phenols are used in disinfectants, biocides, preservatives, dyes, pesticides and medical/industrial chemicals (NSW OEH 2016). They can also be produced through the degradation of organic matter (e.g. plant material) or from other anthropogenic organic chemicals. High concentrations of phenol were detected in MWOO, up to 98 mg/kg and 3+4-methylphenol was detected in approximately 50 of the samples at concentrations up to 71 mg/kg. Phenol is not particularly toxic to humans so health-based investigation levels are high in Australia (the most stringent being 3000 mg/kg for Residential A scenario, accessible soil) but ecological threshold criteria are low (predicted no effect concentration (PNEC) of0.13

mg/kg derived from the European Chemicals Agency - ECHA) – hence Project 3 identified phenol as a priority contaminant in MWOO that could potentially affect environmental health. This chemical is not currently routinely monitored in MWOO, nor is it mentioned in the 2014 Resource Recovery Order.

7.5. Phthalates

Phthalates are semi-volatile chemicals used as plasticisers. They are considered to have harmful effects on the reproductive and endocrine systems (Heudorf et al. 2007). They are released from plastic and other consumer products causing human exposure (Heudorf et al. 2007). Phthalates have been found in many building materials, food packaging, baby care products, children's toys and cosmetics. Preliminary evidence has linked phthalate exposure (especially from wall and floor coverings) in populations to the onset of asthma (Bornehag et al. 2004; Jaakkola & Knight, 2008; Kolarik et al. 2008).

Dibuytl phthalate (DBP), bis-2-ethylhexyl adipate (DEHA) and bis-2-ethylhexyl phthalate (DEHP) are the main plasticisers found in MWOO, with concentrations of up to 2,600 mg/kg measured for DEHP (NSW OEH, 2016). The 2014 Resource Recovery Order requires testing for DBP and DEHP but no threshold concentrations in MWOO or soils have been set. Concentrations of phthalates in MWOO are highly variable and high concentrations are common in some batches (Table 4, Figure 2) – this is not surprising as source separation of plastics was determined to be very poor during the TAC's visit to Facility A.

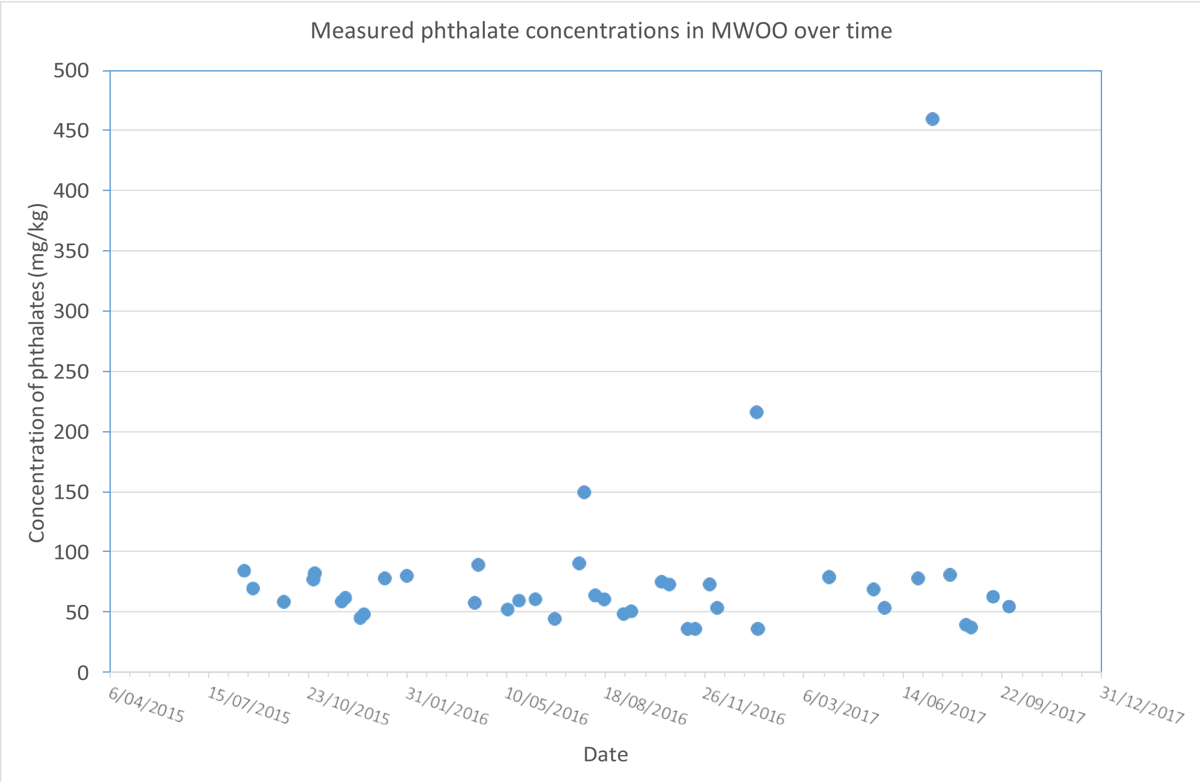

Figure 2. Temporal variation in phthalate concentrations in MWOO (data from Facility A).

Ecological threshold criteria in soils are much lower than thresholds to protect human health, with DBP having the lowest threshold soil concentration (0.05 mg/kg, PNEC from ECHA). Phthalates are not persistent in soils and will degrade over time (Cartwright et al. 2000). This was observed in the field trials reported in Project 2 where DEHP concentrations declined over the 3-year experimental period (Whatmuff et al. 2017). However, concentrations of up to 1 mg/kg were still measured in soil 3 years after application of 10 t/ha.

7.6. Bisphenol A

Bisphenol A (BPA) is commonly associated with plastics. Research on health effects of exposure to bisphenols in children is limited to date, however prenatal exposure to bisphenols has been found to be associated with early childhood wheezing (Spanier et al. 2012). The concerns surrounding BPA are predominately due to its ability to interfere with estrogen receptors (NSW OEH 2016).

Bisphenol A was detected in all MWOO sampled by NSW OEH (Project 3) with concentrations ranging from 4 to 100 mg/kg, with a fraction of the compound being leachable. In the hazard ranking undertaken by NSW OEH (OEH 2016), BPA was regarded as lower ranking than PBDEs and phenols and primarily a threat to soil ecological health based on a (PNEC) from ECHA (no ecological criteria are available for BPA in Australia). There is limited information on the attenuation of BPA and impacts on soil toxicity over time. It is also unclear whether on areas where food is grown BPA could be taken up in plants or adhere to plants which may be consumed.

7.7. Pesticides

Screening for over 100 pesticides in MWOO was undertaken by Project 3 (NSW OEH 2016) with most compounds being undetectable. Thiabendazole, dicamba, 2-methyl-4- chlorophenoxyacetic acid (MCPA) and methylchlorophenoxypropionic acid (MCPP) were the most frequently detected compounds, with MCPA having the highest concentrations in the solid material (1.8 mg/kg) and this pesticide was also the most frequently detected pesticide in the soil leachates. MCPA is not highly toxic to humans and the health-based investigation level in Australia is high (the most stringent being 600 mg/kg for Residential A scenario, accessible soil). There are no ecological criteria for MCPA in soils and Project 3 developed a threshold value of 2.67 mg/kg using lowest published toxicity data and a safety or assessment factor. No pesticides were ranked as posing concern in the risk assessment conducted by NSW OEH (2016).

7.8. Organotin compounds

Tributyl tin (TBT) is regarded as the most toxic organotin compound and it has been used as a wood preservative and for anti-fouling in the marine environment. In the environment it degrades to dibutyl tin (DBT) and monobutyl tin (MBT). These compounds were detected at very low concentrations in the MWOO (0.037 mg/kg) and were not ranked as a high risk to human or environmental health.

7.9. Per- and polyfluorinated alkyl substances (PFAS)

PFAS are a group of chemicals manufactured since the mid-20th century, called per-and polyfluorinated alkyl substances (PFAS). They have been used in firefighting foams and other industrial and consumer products for many decades. The two most well-known PFAS compounds are PFOS (perfluorooctane sulphonate) and PFOA (perfluorooctanoic acid).

PFOS was listed on the Stockholm Convention for Persistent Organic Pollutants in 2009 and as such is internationally recognised as being persistent and bioaccumulative, undergoing long-range transport and having or potentially having adverse effects on human health and the environment (enHealth, 2016, Energy October 2016).

Due to their wide use, and persistence in the environment, and chemical properties that allow easy movement through the environment, PFAS can be found in soil, surface water and groundwater in urban areas at low concentrations.

On 13th March 2018, NSW EPA provided the TAC with new data on PFAS in MWOO, and in biosolid materials for comparison. The key PFAS compounds analysed were:

PFOS
PFOA
PFBS - Perfluorobutyl sulfonate
PFBA – Perfluorobutonoate
PFPeA - Perfluoropentonoate
PFHxS - Perfluorohexyl sulfonate
PFHxA – Perfluorohexonoate
PFHpA - Perfluoroheptonoate
PFNA – Perfluorononanoate
PFDA – Perfluorodecanoate
PFDoA – Perfluorododecanoate
FOUEA - 2H-perfluoro-2-decenoic acid
N-MeFOSE - *N*-Methylperfluorooctanesulfonamidoethanol
N-MeFOSAA - N-methylperfluoro-1-octanesulfonamidoacetic acid
8:2 diPAP - 8:2 perfluoroalkyl phosphate diester
N-E tFOSE - N-ethyl perfluorooctane sulfonamidoethanol

MWOO from Facility D had the greatest concentrations of PFAS (Figure 3) and MWOO from other facilities generally had low, or undetectable, PFAS concentrations.

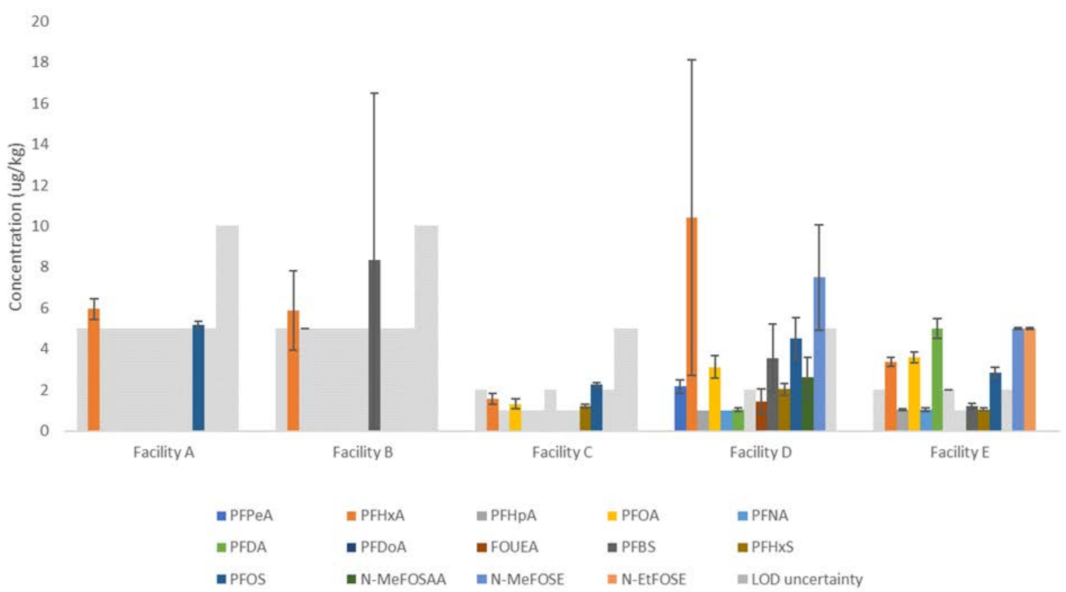

Figure 3. Mean (±SD) concentrations for a suite of PFAS compounds present in MWOO materials (data provided by NSW EPA, 13th March 2018). LOD = Limit of Detection.

In general, concentrations of PFAS were lower in MWOO than in biosolids. The dominant compounds detected in MWOO were PFOS (up to 6.2 µg/kg), PFHxA (up to 26 µg/kg) and N-MeFOSE (up to 11.0 µg/kg). Concentrations of the ∑PFAS varied from non-detect to 47.4 µg/kg. There are no safe threshold criteria determined in Australia for agricultural soils, but the PFAS National Environmental Management Plan (HEPA, 2018) has suggested interim soil screening values for residential areas of 9 µg PFOS or PFHxS/kg to protect humans from food chain exposure, 10 µg PFOS/kg for indirect exposure (to protect from soil ingestion by a secondary consumer) and 1.9 µg PFOS or PFHxS/kg to protect exposure to birds. Use of MWOO under the 2014 Resource Recovery Order at rates of 10 and 140 t/ha (agricultural and minesite use) would not lead to exceedance of the interim soil investigation levels, assuming the maximum concentrations reported in the research are representative.

Leachable concentrations of PFAS, determined using a buffered water extract at pH 4.9 (personal communication NSW EPA), varied from non-detect to 0.68 µg/L, with the highest values found for PFHxA. Maximum concentrations of leachable PFOS and PFOA were 0.07 and 0.10 µg/L, respectively. These compare to freshwater guideline values of 0.13 and 220 µg/L for PFOS and PFOA in slightly-to-moderately-disturbed systems (the most relevant scenario for freshwater in agricultural landscapes). Hence, even allowing for no dilution in the landscape, use of MWOO would not lead to exceedance of the interim freshwater guideline values, assuming the maximum concentrations reported are representative.

7.10. Overall risks from chemical contaminants

In the hazard assessment of NSW OEH (Project 3), predicted contaminant concentrations in soil were compared against human health or ecological (soil) criteria, given two use scenarios – use on agricultural land (10 t/ha application rate) and minesite rehabilitation (140 t/ha application rate). The hazard quotient (HQ) was calculated for each analyte in MWOO (sampled over a period from November 2011 to January 2014).

The first characteristic observed in the hazard ranking was the wide variability in the HQs, as a result of the chemical heterogeneity of the MWOO material sampled at different times (Figure 4).

This indicates the source streams entering the facility are highly heterogeneous, unregulated and therefore there is poor capability to control contaminant concentrations. This was demonstrated by the testing conducted by NSW EPA (Table 5) that indicated several instances of contaminants exceeding the 2014 Resource Recovery Order criteria.

This contrasts to biosolid production where, while the material is not perfectly homogenous, there is more mixing and dilution of any high contaminant concentrations, as well as better control on contaminant inputs through trade waste controls. For high quality MWOO materials, much better source separation is needed prior to wastes being processed/composted.

Even at a low application rate (10 t/ha total), several contaminants had concentrations that could potentially be of concern – PBDEs, phenol, Cu, Al, Mn, Zn and phthalates. The high-risk ranking of Al and Mn is related to the values for ecological screening criteria used for soil - 50 mg/kg and 3.4 mg/kg, respectively.

The threshold for Al in soil was derived from NOAA who used an outdated US EPA Soil Screening Level (SSL), clearly below background values, and hence this HQ should be treated with caution.

Table 5. Summary data for testing of MWOO from AWT facilities (supplied by NSW EPA, 13th March 2018).

	Facilit y A	Facility B	Facility C		Facility D	Facility E
(mg/kg unless otherwise indicated)			**Mine spec**	**Ag. spec**		
Monobutyltin as Sn ng/g	33	14	61	49	13	20
Dibutyltin as Sn ng/g	57	2.6	44	41	2.4	12
Tributyltin as Sn ng/g	610	8.4	13	5.2	6.9	1.4
Antimony (acid extractable)	<3	<3	<3	<3	4	<4
Arsenic (acid extractable)	6	7	<5	5	<4	7
Beryllium (acid extractable)	<1	<1	<2	<2	<1	<2
Boron (acid extractable)	30	10	20	20	30	20
Cadmium (acid extractable)	**8**	<1	3	3	**4**	<2
Chromium (acid extractable)	45	14	30	45	63	30
Cobalt (acid extractable)	6	3	7	6	13	3
Copper (acid extractable)	310	87	230	230	220	180
Lead (acid extractable)	**880**	25	120	130	200	170
Manganese (acid extractable)	420	250	230	240	270	200
Molybdenum (acid extractable)	4	<1	<2	<2	2	<2
Nickel (acid extractable)	38	13	37	42	46	19
Selenium (acid extractable)	<6	<5	<6	<6	<6	<8
Tin (acid extractable)	16	8	39	39	74	27
Vanadium (acid extractable)	8		5	6	6	5
Zinc (acid extractable)	**810**	240	590	600	**940**	350
Mercury µg/kg	380	140	150	150	230	190
Moisture (105°) % w/w	31	23	37	36	31	48
Glass, metal, rigid plastic > 2 mm % w/w	0.47	0.95	2.40	**1.80**	**3.40**	1.30
Plastic - light, flexible, film > 5 mm % w/w	<0.05	0.05	**0.40**	0.06	**0.42**	**0.28**
Fipronil µg/kg	<11	<11	15	15	<11	<11
Thiabendazole µg/kg	8	<5	<5	<5	8	5
3+4-Methylphenol	4.4	8.0	2.2	2.4	2.2	31
Bis-2-ethyl hexyl adipate	<1.2	<2.1	74	61	6.1	8.9
Bis-2-ethyl hexyl phthalate	86	18	250	270	260	370
Dibutyl phthalate	<1.4	<2.6	6.5	<1.6	4.0	5.1

Table 5. Summary data for testing of MWOO from AWT facilities (supplied by NSW EPA, 13th March 2018) - continued

	Facilit y A	Facility B	Facility C		Facility D	Facility E
(mg/kg unless otherwise indicated)			**Mine spec**	**Ag. spec**		
Naphthalene	0.46	<0.52	0.88	0.55	<0.29	<0.39
Phenol	37	9.8	5.3	6.1	5.2	65
Bifenthrin µg/kg	430	630	390	450	190	360
Chlorpyrifos µg/kg	60	70	220	200	<3	70
Permethrin I µg/kg	370	320	410	440	360	320
Permethrin II µg/kg	770	640	920	970	700	570
Tebuconazole µg/kg	110	70	160	120	90	230

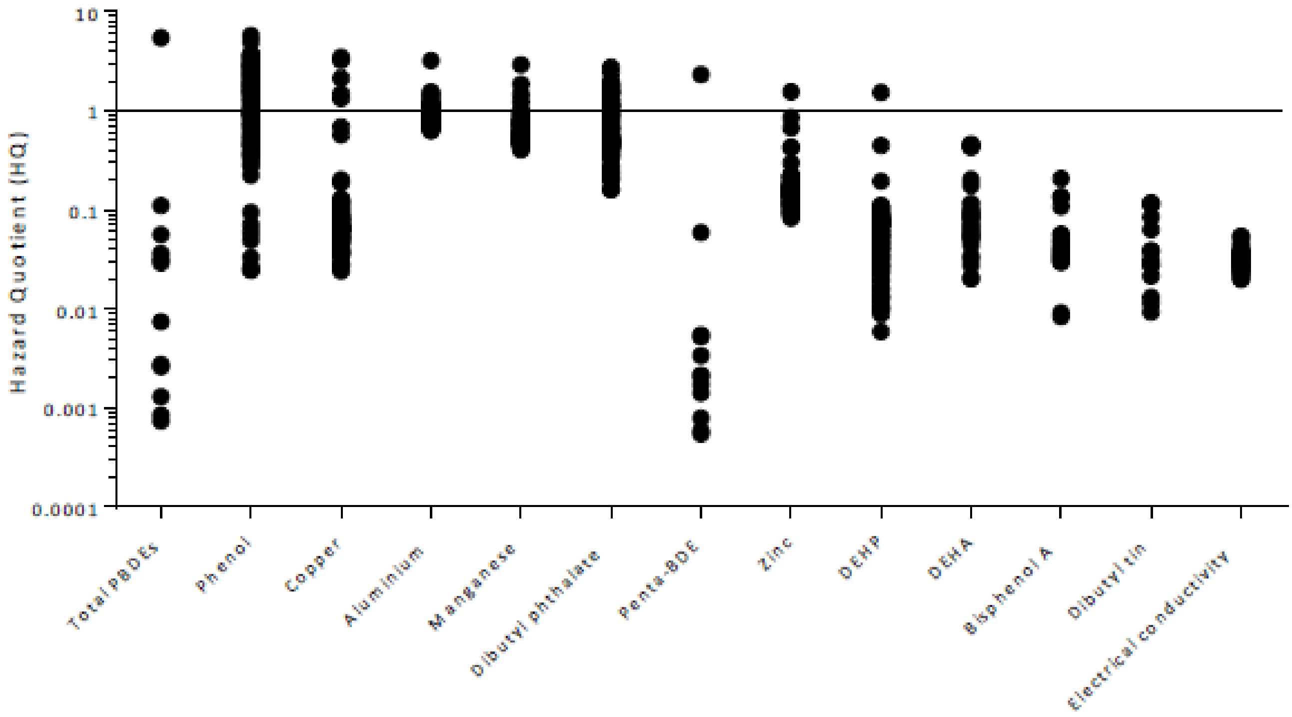

Figure 4. Hazard quotient distribution for soil following application of MWOO at 10 t/ha. All chemical concentrations are compared against terrestrial ecological criteria concentrations, except PBDEs, which are compared against human health criteria. The solid line indicates where HQ = 1 (from NSW OEH, 2016).

The screening level used for Mn (3.4 mg/kg) was derived from a PNEC from ECHA (https://echa.europa.eu/registration-dossier/-/registered-dossier/15553/6/1) that is again clearly below background concentrations (McLaughlin 2000) in soil – Mn is a component of many soil minerals. Hence, the HQ for Mn should also be treated with caution.

The peer review of the NSW OEH Project 2 report also noted this in relation to soil threshold values.

This leaves the major contaminants of concern to be PBDEs, phenol, Cu, Zn and phthalates (DEHP), to which Cd should also be added as most regulatory soil threshold values are not protective of food chain contamination.

If MWOO continues to be used on agricultural land, it is recommended that the metals Cd, Cu and Zn in MWOO be managed using an approach consistent with current biosolid guidelines. This is particularly for those using guidelines consistent with the methodology to develop ecological investigation levels outlined in the Contaminated Sites NEPM (NEPC 2013b) to take into account soil bioavailability issues (WA DEC, 2012) as recommended by the NBRP (Warne et al. 2007).

This would mean that soil metal limits would become more restrictive than current NSW Biosolid reuse guidelines for sensitive soils (acidic, sandy, low CEC and low organic matter soils).

If MWOO continues to be used on agricultural or minesite land, it is also recommended that limits values for PBDEs, phenol and phthalates (DEHP) be developed to ensure safe use of these materials in agriculture to protect the environment (e.g. contaminant runoff) and human health.

8. Detrimental effects of MWOO on soil quality – physical contaminants

One feature of MWOO that sets it apart from other organic waste streams destined for re-use on land (biosolids, chicken compost, manures, etc.) is the presence of physical contaminants due to difficulties in waste component separation during processing. Plastics, metal objects and glass are considered contaminants, as they serve no functional or beneficial purpose within the soil-plant system and have potential to degrade the production system.

The TAC's site visit to the Facility A indicated that significant amounts of physical contaminants were still present in the final MWOO material destined for land re-use. In addition, it was evident that the pre-sorting of input waste prior to composting was not effective in removing a significant quantity of plastic waste.

At the very least, consideration needs to be given to better removal technologies for physical contaminants in MWOO processing, so that grinding is not seen to be a solution for meeting contaminant limits. For plastics, similar comments can be made, and in addition, steps should be taken to move Australia to the use of biodegradable products also having low inherent toxicity hazard.

8.1. Effect of physical contaminants on soil physical condition

Physical degradation mechanisms due to glass and plastic contamination where particulate is > 2.0 mm may include:

- Pore blockage due to straining (particulate size greater than soil pore size)
- Contamination of, or impact on, plant matter and organisms existing within soils (e.g. glass residue on root-based vegetables, worm function etc.)
- Aesthetic implications including reflectance of sunlight (glass) or visible plastics

Where particulate is < 2.0 mm, physical degradation mechanisms due to glass and plastic contamination may include:

- Pore blockage due to infiltration and subsurface adhesion (particulate less than soil pore size)
- Contamination of, or impact on, plant matter and organisms existing within soils as for above.

Offsite impacts of both fractions need to be considered. The < 2.0 mm fraction is highly prone to movement with run-off and likely too small for conventional engineering methods of sediment control. The larger fraction of plastics is also highly prone to run-off with water but may be mitigated by conventional engineering sediment controls. Wind movement of both requires consideration, with the clause requiring no windblown litter from land in the 2014 Resource Recovery Exemption being a reasonable expectation.

Current Resource Recovery Exemption conditions allow a cumulative 10 t/ha (agricultural land), 50 t/ha (non-contact agricultural land) and 140 t/ha for minesite rehabilitation. This means that up to 150 kg/ha and 3500 kg/ha of "Glass, metal and rigid plastics > 2 mm" as well as 20 kg/ha and 350 kg/ha of "Plastics – light, flexible or film > 5 mm" can be applied to agricultural land and minesites, respectively. In evaluating data provided to the TAC, it appears some facilities endeavour to create a single MWOO adhering to the agricultural requirement as the more stringent threshold, although this should not be relied on as industry general practice (small sample size of available data only). Data from Facility A suggest that the maximum quantity of "Glass, metal and rigid plastics > 2 mm" in MWOO is often exceeded, while the maximum quantity of "Plastics – light, flexible or film > 5 mm" is also periodically exceeded (Table 5), within the context of agricultural land application. The quantity of glass, metal and plastics < 2.0 mm is not completely known, although for glass is likely to be more than half (Whatmuff and Gemmel, 2017). This is only one facility but serves to demonstrate current requirements may not be being met at the industry level. The basis for the Resource Recovery Order/Exemption limit values is not clear, and it is concerning that there is no limit for physical contaminants having a diameter < 2 mm for metal, glass and rigid plastics and < 5 mm for light, flexible or film plastics. Furthermore, for plastics, a volumetric-based limit would be more appropriate rather than a gravimetric-based limit, given their very low density.

The projects that were commissioned by NSW EPA with regard to physical contaminants within MWOO were generally rather inconclusive regarding the impact of these physical contaminants. It would appear that this is because the focus of the work was not placed on the physical aspects, with the exception of Project 1 (USyd) and Project 1 (NSW DPI). As a result, both the short- and long- term impact of glass, metal and plastic physical contaminants is mostly unknown and would require further consideration, or active regulation to avoid its occurrence in MWOO. The potential impacts, against the results presented in NSW EPA commissioned projects, are discussed in more detail in the following sections.

8.2. Potential impacts of land application of elevated plastic, metals and glass

8.2.1. Reduction in soil water infiltration rate

The effect of MWOO physical contaminants on the infiltration rates of soils has not been addressed and is likely the most important aspect that needs consideration within the physical context. Further consideration of the effect on soil hydraulic conductivity was also advised as an output of Project 1 (USyd). In that work, they investigated the spatial depth distribution of physical contaminants from MWOO on a Chromosol soil. In this case the physical contaminants considered were > 500 µm diameter, which identifies that the effect of the colloidal fraction of contaminants on soil pores is still largely unknown. The physical contaminant size fraction in Project 1 (USyd) was gravel sized (> 2 mm) and was observed to remain within the depth of application. That is, illuviation transport of these larger fraction particles did not occur. This is somewhat expected as the majority of these particulates are larger than the size of soil pores in all likelihood. This fraction can potentially cause soil pore blockage. Also of concern is the potential for the micro fraction (the < 2 µm particulates, or colloidal particulates). At this juncture, it is very important to note that the gravimetric content of the physical contaminant particulates < 2.0 µm within the MWOO is completely unknown. Previous work has suggested that the colloidal fraction will not cause soil pore blockage, as it is much smaller than the diameter of the pores through which this fraction percolates. However, recent work by Bennett and Warren (2015) investigated the infiltration of clay through soil pores and demonstrated significant reduction (>99%) of the saturated hydraulic conductivity. This was attributed to electrostatic interactions, with adhesion of clay at the soil pore surface compounding over time (< 1000 hours percolation at ≈ 3.6 g/L of particulates) to block pores. This work was conducted in highly compacted soil cores with concentrations likely much greater than might be expected to percolate through agricultural soils. However, it highlights the potential impact of colloidal particles on infiltration rates and suggests that further work is required to investigate the impact of the < 2.0 mm particulates in MWOO, in particular the colloidal fraction (particulates < 2 µm).

8.2.2. Micro plastics (< 2.0 mm fraction)

Micro-plastics are recognised as a potential threat to ecosystems, especially within the context of aquatic environments. Research determining the fate and effects of plastics in fresh and marine waters and sediments has led to increased interest in the degradation rate of plastics. High-density polyethylene (HDPE), polyethylene terephthalate (PET), and polyvinyl chloride (PVC) were identified as the main constituents of the plastic fraction of MWOO and indicated as being highly resistant to environmental degradation. There has been little scientific research undertaken to examine the effects of micro-plastics in the terrestrial environment (Rillig, 2012; Project 1 - CSIRO).

In a 9-month incubation study (Project 1) using 3 soils and MWOO application rates up to 100 t/ha, Williams et al. (2017) found no adverse effects of microplastics on soil microbial numbers, diversity or function, nor did they find any effects on earthworms (chronic toxicity and reproduction, avoidance behaviour), nematodes (survival and reproduction) or plants (wheat seedling emergence and growth). While Project 1 (Williams et al. 2017) considered micro-plastics and their effect on soil chemical fate and ecotoxicology, they did not consider the physical implications of such plastics. However, they note the following: "The nature of the micro-plastics used in this study, being highly resistant to environmental degradation, would suggest that a longer incubation period may be necessary to cover a greater extent of their chemical or physical degradation." Understanding this degradation process will be vital to soil physical function if micro-plastics are allowed at any appreciable level. The breakdown of plastics to much smaller particles should not be considered beneficial, as colloidal particles (< 2 µm) have been demonstrated to cause significant pore blockage, as noted above. Indeed, Bogusz and Oleszczuk (2016) defined microplastics as particles < 2 µm, either produced as particles of microscopic size for a purpose e.g. cosmetics, drug delivery etc. (*primary microplastics*) or those derived from the fragmentation of a wide range of larger plastic materials used for a wide range of purposes (*secondary microplastics*). These microplastics vary in their colour, chemical composition, size, shape, and the physico-chemical properties of their surfaces; like clay particles in soil, they can have a relatively high specific surface and are much more reactive than plastic particles > 2 mm. The EPA/NSW reports (Project 1) revealed very little information the about plastic particles in MWOO compost except for the obvious sizes visible by eye; these particles are probably the least reactive and contribute little to decomposition products - both heavy metals and organic contaminants of the various plastics. It is the *microplastics*, as defined by Bogusz and Oleszczuk (2016), which deserve further research because chemically they are more reactive and are more likely to absorb both heavy metals and organic contaminants, and ultimately become either sinks or sources of these contaminants. In their own right some plastics are actual sources of heavy metals; plastic packaging and inks contain Cd, Hg, Cr and Pb with a European maximum allowable concentration of 100 mg/kg (van Putten, 2011). Indeed, the report of Williams et al. (2017) found that concentrations of several metals were elevated in soil pore waters after addition of plastics to soil.

Although limited, some particle size determinations of MWOO were made in experiments 1 to 4, and quantitatively the fraction of "glass, metal and rigid plastic" >2 mm was small while there were no estimates of plastic particles < 2 mm.

The offsite impacts of micro-plastics need to be considered in terms of both aquatic and terrestrial environments. Project 2 conducted rainfall simulation experimentation, but these data are not sufficient to be conclusive on the safety of application and the magnitude of off-site transport; indeed, the explanation of experimental conditions is incomplete in terms of the rainfall simulator setup and measurement processes.

8.2.3. Glass

In laboratory and glasshouse experiments, Project 1 (Whatmuff and Gemmel, 2017) examined the effects of ground glass (grinding is often employed in MWOO processing to meet limits for physical contaminants) on earthworm avoidance, *Rhizobium* nodulation, clover growth and carrot growth and quality. No adverse effects were observed for earthworm behaviour, *Rhizobium* nodulation, and clover or carrot growth. However, glass particles were observed to adhere to the surface of the carrot tubers (at an application rate for MWOO of 25 t/ha equivalent), leading the authors to recommend further trials to verify this potential serious issue in field trials.

While this application rate is above current 10 t/ha agricultural guidelines, if regulations were to change (to allow the beneficial effects of MWOO to be realised) it is possible that more MWOO would be applied, making this a real concern. An obvious shortfall of the work is that it was laboratory based and constituted from artificially prepared glass treatments. However, the fact that glass is permissible in MWOO used on agricultural land requires that this issue be either further considered experimentally, or the risk avoided by more effective glass removal. If MWOO is to be used on root or tuber crops destined for human or animal consumption, it is imperative that the potential transfer of glass contamination to edible portions be evaluated.
Certainly, the use of hammer-milling or similar mechanical practices, at any point in MWOO processing, should not be allowed to aid in the minimisation of this risk.

While there is no strong evidence that physical contamination of soil with plastics or glass has significant adverse effects on soil microbial or invertebrate function, or on terrestrial plants, there is an issue with allowing soils to be contaminated by persistent contaminants. Persistence is one of the key attributes of any contaminant that raises concerns for environmental or human health (along with bioaccumulation and toxicity). The persistence of physical contaminants in soil means that repeated applications of materials containing these contaminants must be closely scrutinised, due to the uncertainties with regard to long-term effects that are often not expressed in short term research programs.

8.2.4. Aesthetic considerations

There is also an aesthetic aspect to the contamination of soils by persistent physical contaminants – this may change the visual appearance of soils to a form that would be unacceptable to the community. Figure 1 suggests that there is a significant proportion of visible plastic contained in that source of MWOO, which is considered representative of industry MWOO output (personal Communication NSW EPA). Plastics are clearly visible on the soil surface after one addition of MWOO to land (Figure 6), reducing the aesthetic appearance of agricultural soil.
Additionally, with the glass content, there is likely going to be a sun reflectance factor (shine) coming from paddocks where this is applied. The extent of this is unknown to the TAC and should be considered. The aesthetic impact extends beyond the landholder where MWOO is applied, as a regional community relies on aesthetics of its region for tourism and cultural significance. The extent of any impact in this regard is unknown.

Figure 6. Appearance of soil surface after one MWOO application to land at 10 t/ha (photo taken 18th March 2018, courtesy of NSW EPA).

The simplest approach to this is to ensure that plastics and glass are removed at the outset of MWOO processing. Failing this, further information is required to quantify the regional value placed on the aesthetic of agricultural land, as well as non-agricultural land.

9. Human and Plant Pathogens

9.1. Organic Output derived from Mixed Waste

The definition in the Resource Recovery Exemption indicates that mixed waste may contain food-, animal- (including manure) and garden-waste, which comes from residual putrescible organics from households, waste from commercial premises (restaurants, clubs, hotels etc.), and grit from sewage systems.

The Resource Recovery Order requires the organic waste to be pasteurised to significantly reduce animal and plant pathogens and plant propagules. Pasteurisation requirements include:

(a) Appropriate turning of outer material to the inside of the windrow so that the whole mass is subjected to a minimum of 3 turns with the internal temperature reaching a minimum of 55°C for 3 consecutive days before each turn. Where materials with a higher risk of containing pathogens are present, including but not limited to manure and food waste, the core temperature of the material mass should be maintained at 55°C or higher for 15 days or longer, and during this period the windrow should be turned a minimum of 5 times.

(b) Any alternative process to (a) that guarantees the same level of pathogen reduction, and the reduction of plant propagules as in (a). Any such alternative process must be clearly defined in writing and validated by a suitably qualified person prior to claiming compliance with this exemption. A written record of the validation report must be kept for a minimum period of three years.

After pasteurisation, the waste materials undergo biological stabilization for at least 6 weeks (composting and curing) or until biological stability equivalent to that which occurs with 6 weeks of composting and curing is achieved. If the application of the output is greater than 10 tonnes/hectare (dry weight), consumers have to ensure testing for number of chemical contaminants and other materials. There is no requirement to test for microbial pathogens in this Resource Recovery exemption.

The exemptions specify that MWOO can only be applied to land as soil amendments for: the improvement or rehabilitation of minesites, plantation forestry, non-contact agriculture and broad acre agriculture. Further restrictions apply based on land use, volume to be applied, frequency of application, soil pH, slope of the land, buffer zones for protected areas (surface water, drinking water bores and other bores), animal grazing, and harvesting of crops after application.

9.2. Composition of Waste

The composition of municipal solid waste in Australia can vary considerably between jurisdictions, within jurisdictions, within regions as well as over time. Municipal solid waste has a high percentage of food (meat and organics), paper and cardboard, disposable nappies, pet litter and garden waste.

The TAC visited a treatment facility on 22nd September 2017. The TAC observed processes involved in sorting domestic waste, pasteurisation and stabilisation. The committee noted that the waste ready to be pasteurised included disposable nappies, plastics and glass. The end material, which was undergoing stabilisation, had highly visible plastics and glass components.

9.3. Human Pathogens of Concern

The survival of human and animal pathogens in waste will largely depend on the temperature and moisture content of the materials. Other factors that influence their survival include oxygen level, pH, and ammonium content and microbial competition. In general, the higher the temperature and thelonger the storage or treatment time of the composted material, the less likely pathogens are to survive. Most pathogens have short survival times under very dry conditions.

Based on the waste inputs allowed under the 2014 Resource Recovery Order, mixed waste will contain food waste, human and animal faecal matter, and grit from the sewage system which can contribute a multitude of human pathogens to the waste. The MWOO poses a number of risks to human health when used as a soil amendment. Those risks include:

1) Residual pathogens in the final/end material
2) Regrowth of pathogens after treatment or during storage of end material

MWOO may potentially contain a variety of human pathogens and the most common ones reported in the literature are summarised in Table 6 (this is not an exhaustive list of all potential pathogens of concern). The pathogens that can affect human health can be broadly categorised into four groups: Viruses, bacteria, protozoa and helminths.
Table 6. Common pathogens reported in mixed urban wastes.

Viruses

Pathogen	**Disease**
Adenovirus	Conjunctivitis, respiratory infections, gastroenteritis
Coxsackievirus	Aseptic meningitis, gastroenteritis
Norovirus	Gastroenteritis
Rotavirus	Gastroenteritis, infant diarrhoea
Calicivirus	Gastroenteritis
Echovirus	Aseptic meningitis, encephalitis
Astrovirus	Fever, diarrhoea
Hep A virus	Infectious hepatitis
Reovirus	Respiratory infections, gastroenteritis

Bacteria

Pathogen	**Disease**
Salmonella spp	Diarrhoea, fever
Salmonella typhi	Typhoid, Paratyphoid fever
Campylobacter jejuni	Bloody diarrhoea, Guillain-Barré syndrome
Pathogenic E.coli	Diarrhoea, UTI, respiratory infections and pneumonia,
Clostridium perfringens	Diarrhoea, abdominal cramps
Shigella spp	Diarrhoea, fever, and stomach cramps
Vibrio cholera	Cholera
Yersinia spp	Fever, bloody Diarrhoea and abdominal pain
Legionella spp	Pneumonia, Pontiac fever
Listeria spp	Listeriosis

Protozoa

Pathogen	**Disease**
Cryptosporidium parvum	Gastroenteritis
Cryptosporidium hominis	Gastroenteritis
Giardia lamblia	Giardiasis, Diarrhoea
Entamoeba histolytica	Amoebic dysentery, amoebiasis acute enteritis
Toxoplasma gondii	Toxoplasmosis
Balantidium coli	Balantidiasis, diarrhoea, dysentery

Helminths

Pathogen	**Disease**
Taenia spp.	Cysticercosis
Ascaris spp.	Intestinal blockage, impaired growth in children
Ascaris lumbricoides	Ascariasis, digestive and nutritional disturbances, abdominal pain, vomiting
Ascaris suum	Fever, respiratory effects
Strongyloides	Diarrhorea
Necator americanus	Iron deficiency anaemia, cardiac complications, gastrointestinal and nutritional/metabolic symptoms.
Trichuris spp.	Bloody stools, anaemia, growth retardation
Anclostoma duodenale	Anaemia

9.4. Zoonotic Diseases

The diseases that are naturally transmissible from animals to humans are called zoonotic diseases. Most emerging human diseases are zoonotic in nature. Avian influenza, Anthrax, Rabies and Hendra, are examples of zoonotic viral infections which cause serious disease and mortality. Potential pathways exist for these zoonotic pathogens to enter the mixed waste stream and survive in the end material. Major zoonotic pathogens of human health concern are listed in Table 7 (this is not an exhaustive list of all potential pathogens of concern).

Table 7. Major zoonotic pathogens of human health concern.

Viruses

Pathogen	Disease
Avian Influenza	Influenza-like illness, pneumonia and diarrhoea
Swine Influenza	Influenza like Illness (ILI)
Bat Lyssavirus	Flu-like symptoms, paralysis, delirium, convulsions and death
Hendra	Meningitis or Encephalitis

Bacteria

Pathogen	Disease
Salmonella spp	Salmonellosis
Bacillus anthracis	Anthrax
Leptospira spp	Leprospirosis
Listeria monocytogenes	Listeriosis
Coxiella burnetti	Q fever
Clostridium tetani	Tetanus
Francisella tularensis	Tularaemia

Protozoa

Pathogen	Disease
Cryptosporidium spp	Gastroenteritis
Giardia lamblia	Giardiasis, Diarrhoea
Entamoeba histolytica	Amoebic dysentery, Amoebiasis Acute enteritis
Toxoplasma gondii	Toxoplasmosis

Helminths

Pathogen	Disease
Taenia saginata	Taeniasis
Taenia solium	Cysticercosis
Hydatids	Hydatid disease or Echinococcosis
Fasciola hepatica	Gastrointestinal issues, inflammation of liver, gall bladder and pancreas

9.5. Plant Pathogens

A plant pathogen is an organism or virus that can infect and compromise plant health by causing disease. Plant pathogens may be fungi, bacteria, viruses or nematodes, and they have varying levels of host specificity. Plant pathogen inoculum is the biological structure (e.g. spore, conidium, sclerotium, mycelium, cell, egg, cyst, and particle) able to cause primary infection of a plant. Some of these biological structures can survive for a long time in soil and some survive in living plant parts or debris.

A number of plant fungal pathogens and viruses are temperature tolerant. Eradication of some plant pathogens requires temperatures in excess of 68 degrees centigrade and a composting period longer than 20 days. Due to the need for proper mixing and consistently high temperatures for pathogen reduction, some composting systems (windrow) may not be efficient in the eradication of all plant pathogens.

9.6. Human Pathogen Sampling and Results

A limited number of MWOO samples from two different facilities were tested for a number of pathogens as part of the research program. The results were compared to limits set for biosolids. *E.coli* in MWOO were above the prescribed limits for biosolids. A more comprehensive and representative sampling is required to inform the risk assessment.

Additional testing was performed on the MWOO from different AWT facilities in November 2011. The results indicate some of the wastes had unacceptable levels of *E. coli* and faecal coliforms and when compared to the biosolids guidelines.

In 2012 the opinion of the Department of Primary Industries' Principal Research Scientist, Microbiological Diseases and Diagnostics Research was that microbial indicators of faecal contamination in MWOO sampled were "less than optimal" for *Clostridium perfringens* and *E. coli* and faecal coliforms.

9.7. Human Exposure Pathways

There are number of pathways by which humans could be exposed to pathogens in the mixed organic output. The major exposure pathways that need assessment include inhalation, ingestion (food and water) and dermal contact. There may be other relevant exposure pathways and should be explored in the quantitative risk assessment.

9.8. Microbiological Risk Assessment

The enHealth guidelines for assessing human health risks from environmental hazards describe the aim of the microbiological risk assessment is to estimate the level of disease associated with a particular pathogen in a given population under a specific set of conditions and for a certain time frame. It is feasible to undertake a formal quantitative risk assessment that combines scientific knowledge about the presence and nature of pathogens, their potential fate and transport, the routes of exposure of humans and the health effects that may result from this exposure, as well as the effect of natural and engineered barriers and hygiene measures. This knowledge can be combined into a single assessment that allows evidence-based, proportionate, transparent and coherent management of the risks of infectious disease transmission.

As described by the World Health Organisation's (WHO) "Quantitative Microbial Risk Assessment (QMRA): Application for Water Safety Management", QMRA is a formal four-step risk assessment process where each component of the assessment is explicitly quantified (Table 8).

10. Regulations/orders/guidelines for related materials

The EPA regulates the land application of recycled organic wastes through resource recovery orders and exemptions http://www.epa.nsw.gov.au/your-environment/recycling-and-reuse/resource-recovery-framework. For the land application of recycled organic wastes to occur, it must be beneficial and pose minimal risk of harm to the environment or human health. Resource Recovery Orders prescribe responsibilities for the generator and/or processor of the waste, including the final material characteristics required prior to supply for land application.

Table 8. Steps in a Quantitative Microbial Risk Assessment.

Step	**Description**
Problem formulation	The overall context (reference pathogens, exposure pathways, hazardous events and health outcomes of interest) of the risk assessment is defined and constrained in order to successfully target the specific risk management question that must be addressed.
Exposure assessment	The magnitude and frequency of exposure to each reference pathogen via the identified exposure pathway(s) and hazardous events are quantified.
Health effects assessment	Dose–response relationships (linking exposure dose to probability of infection or illness) and probability of morbidity and mortality (depending on the health end-point of the assessment) are identified for each reference pathogen.
Risk characterization	The information on exposure and the health effects assessment are combined to generate a quantitative measure of risk

Resource Recovery Exemptions prescribe responsibilities for the consumer at the land application site and exempt the consumer from certain regulatory requirements such as the need to hold an Environmental Protection Licence or to pay the waste levy. The recycled organic wastes currently applied to land under Resource Recovery Orders and Exemptions are processed animal waste, biosolids, compost, pasteurised garden organics, mulch, solid and liquid food wastes, rapidly decomposed/dehydrated food wastes, treated grease trap waste, and mixed waste organic outputs (MWOO).

Most of these recycled organics are managed under general exemptions. General exemptions are listed on the EPA's website (http://www.epa.nsw.gov.au/your-environment/recycling-and-reuse/resource-recovery-framework/current-orders-and-exemption) and can be used by anyone without further EPA approval, so long as all conditions are fully complied with. General RROs and RREs are designed for frequently produced, well-characterised wastes where the risks surrounding application to land are fully understood.

The EPA can also issue specific Resource Recovery Orders and Exemptions. Specific Resource Recovery Orders and Exemptions can only be used by the legal entities specified in that Order or Exemption. Specific Resource Recovery Orders and Exemptions are often issued to protect commercial-in-confidence process information, or in circumstances where the generation, processing or consumption of the waste is a one-off event or where it is restricted to only one generator, processor, or consumer of the waste.

Resource Recovery Orders and Exemptions contain controls to manage the risks associated with any biological, physical and chemical contaminants present. This section will compare how these contaminants are regulated in different recycled organic wastes. The major control that is contained in all Resource Recovery Orders and Exemptions is a strict definition of the recycled organic waste that dictates what it can contain and what processing it must have undergone.

Some differences between regulatory requirements are due to newer Resource Recovery Orders and Exemptions including updated controls. Documents are periodically reviewed to maintain consistency. The Biosolids Guidelines, on which the Biosolids Resource Recovery Order and Exemption are based, are currently the subject of a major review.

10.1. Biological contaminants

Resource Recovery Orders and Exemptions have controlled pathogens to date through requiring appropriate storage and application of waste, placing limits on the presence of certain pathogens, requiring minimum levels of processing, mandating livestock or harvesting withholding periods following application and restricting the types of land where the waste can be applied (Table 9).

10.1.1. Storage and application requirements

The exemptions for liquid food waste and rapidly decomposed/dehydrated food wastes require that the food waste must be stored in a way that minimises the risk of exposure to and transfer of pathogenic materials from the site by vectors. The exemptions for liquid food waste and treated grease trap waste also specify that the waste must be injected into land between 10 cm and 30 cm below the soil surface, and that the furrows are covered soon after injection. This requirement aims to minimise vector attraction and to prevent wildlife and livestock encountering the waste. The exemption for solid food waste requires that the waste is incorporated into the topsoil by ploughing or mixing so that the waste is completely covered by soil. The biosolids guidelines require biosolids to be incorporated into the soil within 36 hours of spreading.

10.1.2. Limits on certain pathogens

The orders for compost, rapidly decomposed/dehydrated food wastes and biosolids set absolute maximum limits for several pathogens (Table 10). The Biosolids Guidelines, which the biosolids order mandates compliance with, only sets pathogen limits for biosolids meeting Stabilisation Grade A. Biosolids meeting Stabilisation Grade A must also pass initial process verification standards at the start of supply, which consists of enteric viruses being less than 1 PFU (plaque forming unit) per 4 g and helminth ova being less than 1 per 4 g. There are no pathogen limits or monitoring requirements for biosolids meeting the other stabilisation grades.

10.1.3. Process requirements

The Resource Recovery Order for processed animal waste specifies that the waste must have undergone heat treatment sufficient to destroy pathogenic microorganisms. The Resource Recovery Orders for pasteurised garden organics, compost and MWOO specify that the waste must undergo the process of pasteurisation, as a minimum, before supply to a consumer. The Resource Recovery Order for rapidly decomposed/dehydrated food waste requires the waste to undergo at least one full operational cycle in the relevant decomposition/dehydration unit before it is supplied.

The process considerations for biosolids are more flexible. Rather than requiring biosolids to undergo one specific process, the biosolids guidelines list 10 different pathogen reduction processes and 11 different vector attraction reduction requirements. All biosolids intended for land application must undergo at least one pathogen reduction process and at least one vector attraction reduction requirement. The Stabilisation Grade of the biosolids depends on which combination of processes are undertaken. The stabilisation grade then feeds into the classification of the biosolids, which dictates how the biosolids can be used.

Table 9. The controls for biological contaminants in recycled organic wastes.

Recycled organic waste	Storage & application requirements	Limits on certain pathogens	Process requirements	Withholding periods	Land use restrictions
Processed animal waste	-	-	✓	-	-
Biosolids	✓	✓	✓	✓	✓
Compost	-	✓	✓	-	-
Pasteurised garden organics	-	-	✓	-	-
Liquid food waste	✓	-	-	-	-
Manure	-	-	-	-	-
Mulch	-	-	-	-	✓
Solid food waste	✓	-	-	✓	-
Rapidly decomposed/dehydrated food waste	✓	✓	✓	✓	✓
Treated grease trap waste	✓	-	✓	✓	✓
MWOO	-	-	✓	✓	✓

Table 10. The maximum pathogen limits for compost, rapidly decomposed/dehydrated food waste and biosolids.

Recycled Organic waste	Absolute maximum limits				
	Salmonella spp.	***E. coli***	**Faecal coliforms**	***Clostridium perfringens***	***Bacillus cereus***
Compost	Absent in 25g	<100 MPN/g	<100 MPN/g	-	-
Rapidly decomposed/ dehydrated food wastes	Absent in 25g	Absent at limit of detection (MPN/g)	-	Absent at limit of detection (CFU/g)	Absent at limit of detection (CFU/g)
Biosolids meeting Stabilisation Grade A	Absent in 50g	<100 MPN/g	<1000MPN/g	-	-

10.1.4. Withholding periods

Withholding periods for livestock and/or crop harvest following land application of waste are currently required by RREs for biosolids, solid food waste, rapidly decomposed/dehydrated food waste and MWOO (Table 11).

Table 11. The withholding restrictions for biosolids, solid food waste, rapidly decomposed food waste, treated grease trap waste and MWOO.

Recycled organic waste	Grazing restrictions	Cropping restrictions
Biosolids	Animals should not be allowed to graze the land until the landholder is confident that the applied biosolids have been incorporated into the soil to the extent where they cannot be passively or preferentially ingested by grazing livestock	-
Solid food waste	Livestock withholding period of 30 days, except for lactating or new born animals, for which the withholding period is 90 days	-
Rapidly decomposed/dehydrated food waste	Livestock withholding period of 90 days Waste cannot be fed to or come into contact with pigs or ruminants	Contact agricultural crops cannot be grown for 90 days following application
Treated grease trap waste	Livestock withholding period of 30 days	-
MWOO	Livestock withholding period of 30 days, except for lactating or new born animals, for which the withholding period is 90 days	Crops cannot be harvested for 30 days after application

The specific exemption for MWOO does not have any cropping restrictions because the current land use of mine rehabilitation does not include agriculture.

10.1.5. Restrictions on land use of recycled organics

The Resource Recovery Exemptions for rapidly decomposed/dehydrated food waste, biosolids, mulch and MWOO contain land use restrictions. Rapidly decomposed/dehydrated food wastes cannot be applied at high public contact sites, such as childcare centres and children's playgrounds. The land use types to which biosolids can be applied depend on the classification of the biosolids. The lower the classification, the greater the restrictions that apply. Mulch that contains any weed, disease or pest cannot be applied to land in ecologically sensitive areas. Treated grease trap waste cannot be applied to land with certain characteristics, or to land within buffer zones for certain protected areas. MWOO cannot be used in urban landscaping, at public contact sites, in home lawns or gardens, in potting mix or in turf production.

10.1.6. Physical contaminants

Physical contaminants include glass, metal, rigid plastics, film or flexible plastics, and polystyrene. They are controlled in Resource Recovery Orders by placing limits on the maximum quantity of certain contaminants (which may be zero) and prohibiting the mechanical size-reduction of physical contaminants. and Table 13 summarise the limits applied to different recycled organic wastes.

Table 12. The controls for physical contaminants that are in place for recycled organic wastes.

Recycled organic waste	Contaminants prohibited	Contaminants limited	Mechanical size reduction prohibited
Processed animal waste	-	-	-
Biosolids	-	✓	-
Compost	-	✓	✓
Pasteurised garden organics	-	✓	✓
Liquid food waste	✓	-	-
Manure	-	-	-
Mulch	✓	-	-
Solid food waste	✓	-	-
Rapidly decomposed/dehydrated food waste	✓	-	-
Treated grease trap waste	✓	-	-
MWOO	-	✓	-

Table 13. The maximum limits for physical contaminants in compost, pasteurised garden organics and MWOO.

Recycled organic waste	Maximum limit for glass, metal and rigid plastics >2mm	Maximum limit for light, flexible or film plastics >5mm
Compost	0.5% by weight	0.05% by weight
Pasteurised garden organics	0.5% by weight	0.05% by weight
MWOO	2.5% by weight for minesites 1.5% by weight for plantation forestry, non-contact agriculture and broad-acre agriculture	0.25% by weight for minesites 0.2% by weight for plantation forestry, non-contact agriculture and broad-acre agriculture

10.1.7. Prohibition on mechanical grinding

The orders for compost and pasteurised garden organics prohibit processors from using methods such as hammer milling, crushing or grinding to mechanically reduce the size of physical contaminants. This control was put in place to ensure that processors remove physical contaminants from the waste rather than just reducing them in size to avoid detection (i.e. analytical methods cannot detect glass, metal and rigid plastics <2 mm or light, flexible and film plastics < 5 mm in size).

10.1.8. Chemical contaminants

Chemical contaminants are controlled in Resource Recovery Orders through limiting application rates to the agronomic rate, specifying absolute maximum application rates, placing limits on the maximum concentration of certain contaminants (Table 14), and by placing maximum concentration limits in soil at the application site.

Table 14. The controls for chemical contaminants that are in place for recycled organic wastes.

Recycled organic waste	Application at a calculated rate	Absolute maximum application rates	Average concentration of chemical contaminants	Maximum concentrations of chemical contaminants
Processed animal waste	✓	-	-	-
Biosolids	✓	-	-	✓
Compost	-	-	-	-
Pasteurised garden organics	-	-	-	-
Liquid food waste	✓	-	-	-
Manure	-	-	-	-
Mulch	-	-	-	-
Solid food waste	✓	-	-	-
Rapidly decomposed/dehydrated food waste	✓	-	-	-
Treated grease trap waste	-	✓	✓	✓
MWOO	-	✓	-	✓

As discussed earlier, the land application of recycled organic wastes must be beneficial. If chemical contaminants are present, application rates must consider the risk of environmental impacts from contaminants and balance these risks against the benefit of land application.

10.1.9. Application at a calculated rate

The Resource Recovery Exemptions for processed animal waste, liquid food waste, solid food waste and rapidly decomposed/dehydrated food wastes require the consumer to calculate application rates prior to the waste being land applied. The application rate must be equal to or less than the agronomic rate for the most limiting factor.

The Resource Recovery Exemption for biosolids specifies that the allowable biosolids application rate is determined by calculating the CLBAR (the rate at which biosolids can be applied without exceeding the maximum allowable concentration of contaminants in the soil) and the NLBAR (the rate at which biosolids can be applied without exceeding the annual nitrogen requirements of the crop or vegetation grown on the land). The maximum application rate is then the lower of the CLBAR or the NLBAR.

10.1.10. Absolute maximum application rates

The general Resource Recovery Exemption for MWOO sets absolute maximum application rates depending on the land-use of the application site (Table 15).

Table 15. The maximum application rates for MWOO.

MWOO Resource Recovery Exemptions	Maximum application rate (t/ha)		
	Mine sites	**Plantation forest/non-contact agriculture**	**Broad acre agriculture**
General exemption	140	50	10

The Resource Recovery Exemption for treated grease trap waste specifies maximum application rates based on the oil and grease content of the waste (Table 16).

Table 16. The maximum application rates for grease trap waste.

Oil and grease content (%)	Maximum application rate (t/ha wet weight)
≥50	100
<50	120
<40	150
<30	200
<20	300
<10	600

10.1.11. Maximum concentrations of chemical contaminants

In the general Resource Recovery Orders for biosolids and treated grease trap waste, and the general and specific Resource Recovery Orders for MWOO, both metals and organic contaminants are controlled through maximum concentration limits for selected contaminants (Table 17). Resource Recovery Orders for MWOO also require testing of other metals (antimony, beryllium, boron, cobalt, manganese, molybdenum, tin and vanadium) and organics (total polycyclic aromatic hydrocarbons, phthalates, non-scheduled pesticides and monobutyltin), but there is no maximum limit set on their concentration. Resource Recovery Orders for Biosolids and MWOO also require soil testing at the application site and set maximum soil concentrations for a number of contaminants, which if exceeded prevent further land application at that site.

10.1.12. Average concentrations of chemical contaminants

The Resource Recovery Order for treated grease trap waste also sets average concentration limits for chemical contaminants (Table 18)

Table 17. The absolute maximum concentration limits of chemical contaminants in biosolids, treated grease trap waste and MWOO.

Recycled Organic Waste	Absolute maximum concentration (dry weight in mg/kg)												
	Arsenic	**Boron**	**Cadmium**	**Chromium (total)**	**Copper**	**Lead**	**Mercury**	**Nickel**	**Selenium**	**Zinc**	**DDT/ DDD/ DDE**	**Other pesticides[1]**	**PCBs**
Biosolids Grade A	20	-	3	100	100	150	1	60	5	200	0.5	0.02	0.3
Biosolids Grade B	20	-	5	250	375	150	4	125	8	700	0.5	0.2	0.3
Biosolids Grade C	20	-	20	500	2000	420	15	270	50	2500	1	0.5	1
Biosolids Grade D	30	-	32	600	2000	500	19	300	90	3500	1	1	1
Treated grease trap waste	20	60	1	100	250	100	1	60	5	350	-	-	-
MWOO	20	-	3	100	375	420 (mines) 250 (everything else)	4	60	5	700	0.5	0.2	0

[1]Other pesticides means Aldrin, Dieldrin, Chlordane, Heptachlor, Hexachlorobenzene (HCB), Lindane, and Benzene Hexachloride (BHC)

Table 18. The maximum average concentration limits of metal chemical contaminants in treated grease trap waste.

Recycled Organic Waste	**Maximum average concentration (dry weight in mg/kg)**									
	Arsenic	**Boron**	**Cadmium**	**Chromium (total)**	**Copper**	**Lead**	**Mercury**	**Nickel**	**Selenium**	**Zinc**
Treated grease trap waste	10	30	0.5	50	150	50	0.5	30	2.5	200

11. Summary

It is clear the current use of MWOO on broadacre agricultural land, with application rate restricted to 10 t/ha, could not be classified as beneficial re-use in terms of improved crop production or beneficial effects on soil chemical or physical quality. Higher, and/or repeat, application rates are needed for the material to have any significant effects on crop growth and quality, and on soil chemical and physical quality.

It is also clear that higher application rates run the risk of greater contamination of soils by metals, persistent organic chemicals, and physical contaminants and under the NSW draft policy provided to the TAC for beneficial re-use or recovered waste materials, no net accumulation of contaminants is stated as a goal. The current use of MWOO would not conform to this draft policy goal.

Land application of MWOO is undertaken where no information on the quality of the receiving soils is known. This leads to a risk of increased concentrations of persistent contaminants in the environment, which may limit land use options, and present additional risks if land use changes.

Risks due to the use of MWOO to rehabilitate minesites was not a focus of the NSW EPA research program. In most cases, minesites generally have soils that have elevated metal concentrations, often low pH and low levels of organic matter. The risk pathways for human or ecological exposure will be very different to agricultural land - MWOO could provide significant benefits and fewer risks in these situations. However, depending on final land use, and depending on future NSW EPA policy on retaining multifunctionality of land in perpetuity (e.g. rehabilitated mined land could become agricultural land in the future), risks may need to be assessed using a default agricultural land use scenario.

The risk assessment for chemical contaminants in the material raises concerns regarding the effects of several contaminants for broadacre agriculture. Some of these (Cd, Cu, Zn) can be managed using current and proposed frameworks/guidelines for biosolids using approaches outlined in the National Environment Protection (Assessment of Site Contamination) Measure, but for others (PBDEs, phenol, phthalates) significant concern for human and environmental health remain and suitable control measures are needed.

The presence of physical contaminants in MWOO also raises significant concerns in terms of human and animal health (glass), as well as concerns for aesthetic quality of soils and soil physical quality degradation (plastics). Glass, PBDEs and metals are persistent in soils. Persistence is one of the key attributes of any contaminant that raises concerns for environmental or human health (along with bioaccumulation and toxicity).

Little data were available to perform a robust risk assessment for pathogens in MWOO. Risks appear low, but insufficient sampling/analysis and routine monitoring has been undertaken to allay concerns.

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