Alternative waste treatment research program

Project 3: Assessing the toxicity of mixed waste organic output leachates

Final Report

Prepared by the New South Wales Office of Environment and Heritage, Environment Protection Science Branch

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Prepared for the New South Wales Environment Protection Authority, Waste Strategy and Innovation Section

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* This report has been amended for public release. Use of the term ‘compost’ has been changed to ‘organic outputs’ in the title of the project and the title of the research program. This has been done for consistency with current terminology. An error in Table A1 has also been corrected.

List of abbreviations

2,4-D	2,4-dichlorophenoxyacetic acid
2,4,5-T	2,4,5-trichlorophenoxyacetic acid
4NP	4-nonylphenol
4OP	2-octylphenol
4tOP	4-*tert*-octylphenol
°C	degrees Celsius
µg	microgram
µm	micrometre
µS	microsiemens
ACL	added contaminant level
ADWG	Australian drinking water guidelines
ANZECC	Australian and New Zealand Environment and Conservation Council
AWT	alternative waste treatment
BPA	bisphenol A
CCME	Canadian Council of Ministers of the Environment
CEC	cation exchange capacity
cm	centimetre
cmol$_c$	centimoles of charge
DAF	dilution-attenuation factor
DBT	Dibutyl tin
DEHA	bis-2-ethylhexyl adipate
DEHP	bis-2-ethylhexyl phthalate
DOC	dissolved organic carbon
DT50	half-life; time taken for the concentration to reduce by 50%
dS	decisiemen
EC	electrical conductivity
EC10	The concentration where 10% of the test species are effected
EC30	The concentration where 30% of the test species are effected
EC50	The concentration where 50% of the test species are effected
ECHA	European Chemicals Agency
Eco-SSL	ecological soil screening level
Eh	Redox potential
EIL	ecological investigation level
F1, F2, F3 and F4	The first (F1), second (F2), third (F3) and fourth (F4) fractions of column leachates
FRP	free reactive phosphorus
g	gram
GC	gas chromatography

HFO	hydrous ferric oxide
HIL	health investigation level
HPLC	high-performance liquid chromatography
HQ	hazard quotient
HQ_{max}	maximum hazard quotient
IRC	interim remediation criteria
kg	kilogram
Koc	organic carbon water partitioning coefficient
Kow	octanol water partitioning coefficient
L	litre
LOQ	limit of quantification
LOEC	lowest observed effect concentration
m	meter
MBT	monobutyl tin
MCPA	2-methyl-4-chlorophenoxyacetic acid
MCPP	methylchlorophenoxypropionic acid
mg	milligram
mL	millilitre
MS	mass spectrometry
MWOO	mixed waste organic outputs
n	number of samples
NATA	National Association of Testing Authorities
NEPM	National Environmental Protection Measure
ng	nanogram
NICNAS	National Industrial Chemicals Notification and Assessment Scheme
NOAA	National Oceanic and Atmospheric Administration
NOEC	no observed effect concentration
NOM	natural organic matter
NOx-N	sum of nitrate and nitrite
PAH	polycyclic aromatic hydrocarbon
PBDE	polybrominated diphenyl ether
PCB	polychlorinated biphenyl
PFOA	perfluorooctanoic acid
PFOS	perflorooctance sulfonate
pH	negative logarithm of hydrogen ion concentration
PFC	perfluorinated compound
PNEC	predicted no effect concentration
QA/QC	quality control and quality assurance
RRE	Resource Recovery Exemption

RRO	Resource Recovery Order
RSD	relative standard deviation
RSE	relative standard error
SD	standard deviation
SE	standard error
SE1, SE2, SE3, SE4, SE5	Sampling events 1-5
SQG	soil quality guideline
SQG_E	environmental soil quality guideline
SQuiRT	screening quick reference tables
SSD	species sensitivity distribution
TBT	tributyl tin
TIE	Toxicity Identification Evaluation
TKN	total Kjeldahl nitrogen
TOC	total organic carbon
TV	trigger value
USEPA	United States Environmental Protection Agency
WQG	water quality guidelines

Executive summary

This project final report has been prepared for the NSW Environment Protection Authority (EPA), as part of the 'Alternative Waste Treatment – Mixed Waste Organic Output Trials' research program funded by the NSW Environmental Trust. It presents results from a project chemically characterising alternative waste treatment (AWT) mixed waste organic output (MWOO) solids and leachates, and investigates the ecotoxicology of leachates. These data were also then considered in a screening assessment and detailed hazard assessment to identify chemicals of potential concern for ecological and human receptors. The results from the experimental component of this project are presented in detail in two Progress Reports (2013 and 2014). The experimental objectives were to:

1. Chemically characterise MWOO solid material over a range of climatic seasons
2. Determine the potential for chemicals to be mobilised from MWOO that may contaminate groundwater and surface waters
3. Assess the toxicity of leachates generated from representative MWOO to aquatic organisms and identify the chemicals responsible for the toxic effects

This report provides a summary of the project and experimental results (as reported in the 2013 and 2014 Progress Reports). Following this, the data have been assessed to identify chemicals, groups of chemicals or chemical parameters (for example electrical conductivity) that are considered high priority that should be considered in future experimental and/or risk assessment work. This was done considering human and environmental exposure pathways to both MWOO solids and leachates. The objectives of this report are to:

1. Provide a summary of experimental work undertaken for the project (Part I)
2. Conduct a preliminary screening assessment of the data to remove chemicals that are considered to be of negligible concern to the environment and human health at concentrations found in MWOO solids and leachates (Part II)
3. Conduct a detailed hazard assessment and data quality assessment to identify specific chemicals, groups of chemicals or chemical parameters as high priority that can be the focus of future risk assessment work using realistic exposure scenarios (Part III)
4. Undertake an additional assessment phase for the high priority chemicals that considers different land application rates and predicted soil pore water concentrations (Part IV)
5. Summarise potential risk mitigating factors that should be considered in future risk assessment work (Part V)

This project is a component of a larger research program that will provide information to assist in the review of the requirements for land application of MWOO in NSW. The projects in the research program are as follows:

- Project 1 – Assessing the impacts of physical contaminants in MWOO on the soil environment
- Project 2 – Large scale field trial assessing the impacts of MWOO using field based crop/soil responses
- Project 3 – Assessing the toxicity of MWOO leachates (this project)
- Project 4 – Assessing the behaviour of MWOO on different NSW soils.

The evaluation and assessment of data in this report was conducted following a tiered approach. Following each tier, chemicals of low concern were removed and not considered further, allowing for a more detailed assessment to be conducted on the chemicals of most concern. The approach used is summarised in Figure 1 as a flow chart.

Throughout the study, MWOO were sampled from two facilities in NSW (Facility A and B). Sampling was conducted over five sampling events (SE1-SE5) that covered a range of climatic seasons between November 2011 and January 2014. The chemicals that could potentially be mobilised from the material were determined by generating leachates. This was done using two methods, a batch extraction, which used a constant solid to liquid ratio (1:20) and column leachates, which generated four subsequent leachate fractions (F1-F4) collected over 7 days. Both the solids and leachates were subject to a range of chemical analyses including, general chemical parameters, macronutrients, inorganic elements, major anions and sulfide, polycyclic aromatic hydrocarbons (PAHs), phenolic compounds, chlorobenzene and nitrobenzene compounds, plasticisers, pesticides, polychlorinated biphenyls (PCBs), alkylphenols, bisphenol A (BPA), organotins, polybrominated diphenyl ethers (PBDEs) (flame retardants), polyfluorinated compounds (PFCs) and asbestos. Although this list covers a number of possible contaminants that might be present in MWOO, the actual list is likely to be more extensive than what could be measured as part of this project. Additional sampling and testing may be required in future to determine concentrations of other chemicals that may be of concern.

In all of the solid samples analysed, chlorobenzene and nitrobenzene compounds, PCBs, PFCs (indicative only due to small sample size) and asbestos were below the limit of quantification (LOQ). Chemicals from the remaining groups were detected in the solid material and/or the leachates throughout the study. The frequencies of detection and concentrations varied considerably for the different chemicals. It was particularly noted that the solid material had a high salinity, which was demonstrated by measurements of electrical conductivity (EC) up to 14 dS/m.

Aquatic toxicity testing of the leachates (batch and column) was conducted with three test species, the cladoceran *Ceriodaphnia dubia*, the bacteria *Vibrio fischeri* and the microalga *Pseudokirchneriella subcapitata*. The F1 fraction was consistently the most toxic with <1 to 22% leachate in samples causing a 50% reduction in a test response (EC50). The toxicity of the batch extraction samples were roughly consistent with the F2 fraction from the column leachates. Toxicity identification evaluation (TIE) was also undertaken using the F1 column leachates. This process indicated that ammonia, sulfide and major ions (measured as EC) were contributing to the overall toxicity of the leachates. Due to the wide range of chemicals that were identified in the material and the leachates, and the toxicity of the leachates that was observed, the chemistry data from the project was assessed further to identify high priority chemicals (Part II and Part III).

In Part II, all of the chemicals quantified in the MWOO solid and leachate samples were subject to a preliminary screen to remove chemicals of negligible concern. For the solid material, this was done by comparing the 95th percentile of concentrations against criteria concentrations that were protective of ecological and human receptors. For the leachates, this was done by comparing the maximum concentration from the F1 fraction of the column leachates against criteria concentrations that were protective of ecological, human and agricultural (stock drinking water and irrigation water) receptors. This is a highly conservative screen and was the first phase in a tiered approach that was used to identify chemicals for a more detailed assessment in Part III. The criteria concentrations were primarily guidelines from Australia, however, other sources were used when Australian values were not available. This preliminary screening process identified a range of chemicals that were then the focus of a subsequent detailed hazard assessment phase. The chemicals that did not exceed the criteria concentrations were not considered further as they were considered to be of negligible concern. There were a number of chemicals for which screening could not be completed, as no criteria concentrations were available. These chemicals were excluded from further assessment, however, they should be assessed when more information becomes available.

In Part II, an additional preliminary screen for secondary poisoning was conducted to identify organic compounds that were detected in the MWOO that might have to potential to biomagnify. This screen identified 8 compounds in the MWOO that have the potential to biomagnify, including PAHs, plasticisers, alkyphenols and PBDEs. These compounds should be considered further for their secondary poisoning risk in future risk assessment work.

In Part III, the chemicals that were not removed through the preliminary screen were assessed in more detail by determining:

1. The maximum exceedance of the criteria concentration – quantified as a maximum hazard quotient (HQ_{max}) (using the 95th percentiles concentration for the solids and the maximum concentration for the leachates)
2. The proportion of measured concentrations that exceeded the criteria concentration – quantified as a percentage of concentrations with HQ values > 1
3. The reliability of the criteria concentrations
4. The data variability and confidence of chemical concentrations measured in the laboratory.

These four factors were considered together using a scoring system to assign each chemical a priority group (high, medium or low priority) for each receptor in the different media (solids and leachates). The chemicals were categorised as high priority if HQ_{max} was > 100, or if HQ_{max} was > 10 and there were 100% of samples with HQ > 1. The medium and low priority chemicals were then determine by summing scores based on the % of samples with HQ > 1, the reliability of the criteria concentration and the data variability/confidence. It is important to note that this type of assessment does not consider combined effects of co-occurring chemicals, however the co-occurrence of the chemicals in the leachates was assessed through the toxicity testing.

The chemicals that were identified as being high priority to the environment and human health through this process are summarised in Table 1. This included a range of metals, plasticisers, several pesticides, phenol, BPA, PBDEs, nutrients, sulfide and EC. The concentrations of PBDE from one facility were of particular concern due to the persistence and toxicity of these compounds. PBDE (except deca-BDE) are all listed on the Stockholm Convention on Persistent Organic Pollutants, highlighting the global concern about these compounds.

Although the high priority chemicals identified through this process are considered to be the greatest concern to the environment and human health it does not necessarily mean that the chemicals pose a risk. Instead, this list if high priority chemicals should be considered as the first iteration of a detailed risk assessment process. This is because the identification of high priority chemicals was a highly conservative assessment that assumed exposure to 100% MWOO solids or leachates. A number of the chemicals categorised as high priority are already monitored in NSW MWOO under the current resource recovery order (RRO). Depending on the outcome of a detailed risk assessment that considers relevant exposure scenarios and mitigating factors, in the future it may be justified to implement requirements for analysis of some of these chemicals that are not currently in the RRO and derive MWOO threshold limits for these.

In Part IV of the report, the high priority chemicals were assessed further by comparing more realistic exposure concentrations to the criteria concentrations. For the solid material this was done by converting the concentrations in the MWOO to concentrations in soil following land application at 140 and 10 t/ha. Following this, to assess the hazard to aquatic receptors, soil porewater concentrations were estimated at the two land application rates. The resulting soil and porewater concentrations were then compared to criteria concentrations. The results from this additional assessment can be used to support the selection of high priority chemicals. The outcomes of this assessment showed that some chemicals may be considered very high priority. This included aluminium, manganese, zinc, phenol, dibutyl phthalate, penta-BDE and total PBDEs for terrestrial receptors and aluminium, chromium, copper, lead, zinc and phosphorus for aquatic receptors. As expected, the potential risk of the chemicals was considerably lower following land application at 10 t/ha, however these results need to be considered along with application rates that are needed to show an agronomic benefit.

It is acknowledged that in the environment, following land application of MWOO, there will be a range of mitigating factors that are likely to reduce the risk posed both at the site of application or off site through leachate or surface run-off transport. These were not considered in the hazard assessment conducted in the project, however Part V of this report provides a qualitative discussion of a number of these factors with a particular focus on the chemicals identified as high priority following Part III. The key mitigating factors discussed include: the persistence of chemicals in soil following land application of MWOO; the effects of bioavailability and speciation; and, physical and geological factors affecting leachate transport. All of these factors have the potential to mitigate the risks associated with chemicals in MWOO following land application and should be considered to determine relevant exposure scenarios for this material in future risk assessment work.

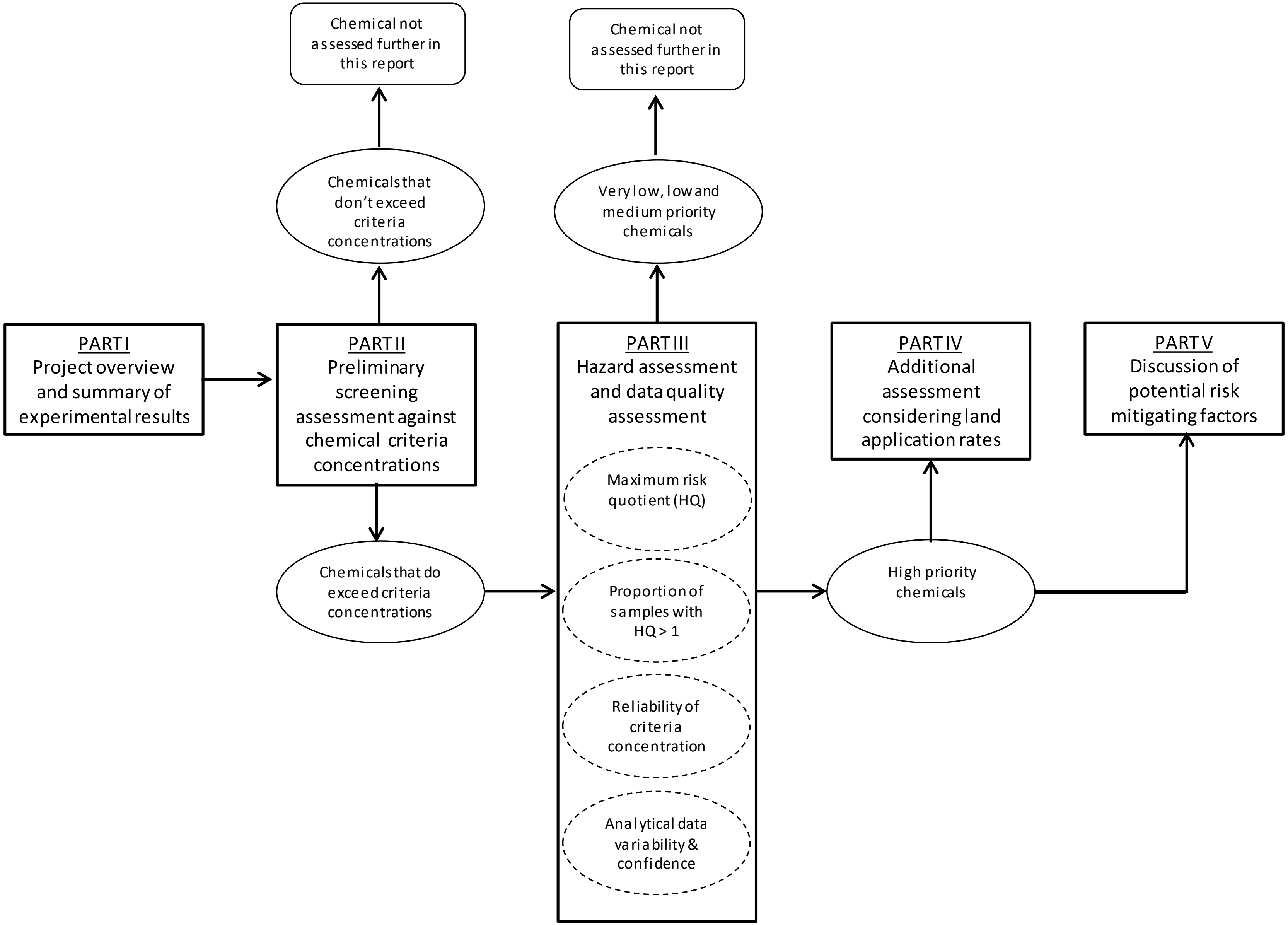

Figure 1: Final Report data evaluation and assessment

Table 1: Summary of chemicals and other parameters categorised as high priority for the exposure of each receptor to the solid material or leachates

Solid material		Leachates			
Ecological	Human health	Ecological	Human health	Livestock drinking water	Irrigation water
Aluminium*	PBDEs*	Aluminium*	Antimony	Copper	Copper
Copper		Barium	Arsenic		Iron
Manganese*		Cadmium	Cadmium		Manganese
Zinc*		Chromium*	Lead		Molybdenum
Phenol*		Cobalt	Nickel		Nickel
Bis-2-ethylhexyl adipate		Copper*			Dicamba
Bis-2-ethylhexyl phthalate		Iron			Phosphorus
Dibutyl phthalate*		Lead			Electrical conductivity
Bisphenol A		Mercury			
Dibutyl tin		Nickel			
Penta-BDE*		Tin			
Electrical conductivity		Zinc*			
		Sulfate			
		Sulfide			
		MCPA			
		Ammonia			
		Nitrate			
		Phosphorus*			
		Electrical conductivity			

* Identified as very high priority from additional assessment presented in Part IV

Recommendations

Based on the outcomes of this project it is recommended that the EPA:

1. Undertake a detailed risk assessment focusing on the chemicals that were categorised as high priority

The outcomes of this report should be used as the first phase of a risk assessment to indicate chemicals of concern in MWOO. This risk assessment should focus on the high priority chemicals (or parameters) from this report and consider relevant exposure scenarios that relate specifically to the requirements for land application in the resource recovery exemption. This assessment should also include results from the other projects in the program where suitable and the outcomes should be used to assist in determining if testing and analysis for additional chemicals should be required under the resource recovery order along with threshold limits for additional chemicals.

2. Require monitoring of PBDEs in MWOO and determine a threshold concentration for PBDEs that is protective of the environment and human health

The concentrations of total PBDEs in MWOO from one of the facilities (Facility A) were approximately 700-times higher than the 1 mg/kg health investigation levels (HIL) used for contaminated sites assessment. In contrast, the material from the other facility had PBDE concentrations that were all less than 1 mg/kg. With the exception of deca-BDE, the PBDE compounds are listed on the Stockholm Convention on Persistent Organic Pollutants, as they are persistent, toxic and bioaccumulative. This highlights the global concern about these compounds. Based on this, all facilities should be required to monitor PBDEs and ensure concentrations can be reduced to a suitable level.

3. Consider the implications of high salt loads (measured as EC) that are readily leachable, on long term soil health and impacts on receiving waters

The concentrations of salt (measured as EC) were up to 14 dS/m in the solid material (using a 1:5 soil to water extract) and 11 dS/m in the F1 fraction from the column leachates. The effect of these levels on soil health are of particular concern if repeat applications are used and therefore should be investigated. In addition, EC was identified as high priority for ecological aquatic receptors and use of leachate as irrigation water and major ions (measured as EC) were highlighted through the TIE process as being a primary toxicant in the leachates. Therefore, the impacts on receiving waters and the possibility that these high salt loads may reach receiving waters should be further considered in a more detailed risk assessment.

4. Require that nitrogen levels in the MWOO and the nitrogen crop requirements be considered when land applying MWOO

Both ammonia and nitrate were prioritised as high risk to aquatic ecosystems following land application of MWOO, based on the concentrations found in the leachates. Due to this, a better understanding of the effect of MWOO on soil nitrogen cycling is required and it is recommended that crop nitrogen requirements be considered when determining land application rates to ensure that the risks posed by nitrogen leaching are minimised.

5. Consider the persistence of organic compounds in soil following land application of MWOO

Information on the likely persistence of organic compounds in soil following land application of MWOO is sparse. However, a number of the organic compounds identified as high risk from this study are also known to persist in the environment (e.g. PBDEs). The expected persistence of these compounds following land application of MWOO should be determined and the persistence of these compounds should be taken into account when considering re-applications of MWOO

6. Consider further testing and analysis of chemicals that could not be measured as part of this study or where only preliminary testing was conducted

Although quite an extensive list of chemicals was analysed for in both the MWOO solids and leachates there will be many chemicals that were not measured or were only subject to preliminary measurements. Further testing of the chemicals should be conducted. These include:

- Perfluorinated compounds (PFCs) – only analysed for in two samples, which were both below quantification limits. Due to the high persistent and human health risks associated with these compounds and the reduction in detection limits since this analysis, additional sampling and analysis is recommended
- Bisphenol A (BPA) (leachates) – only preliminary analysis of BPA in the leachates was conducted for this study. Due to the elevated concentrations of this compound found in the solid material and the high risk that was identified from the solid material, it is recommended that the potential for this chemical to be mobilised from MWOO be investigated further. This may be reconsidered if further risk assessment work concludes that this compound is of low concern.
- Other chemicals identified by Wilson et al. (2014) including:

  - Anilines
  - Nitrotoluenes
  - Chlorinated paraffins
  - Personal care products, pharmaceuticals and steroids (e.g. triclosan, triclocarban and synthetic musks).

7. Undertake an assessment of risk posed to human health from biological contaminants

This study and hazard assessment did not consider the potential exposure of humans to biological contaminants (pathogens) that may be contained in the material. Some preliminary analysis of pathogens in the MWOO was undertaken as part of this study (presented in progress reports), however, these data were considered indicative only. The primary pathway of concern is the direct contact through handling the material. It is recommended that a more detailed sampling and assessment of biological risks be conducted in a separate study, to address this issue more thoroughly than was possible in this project.

Part I: Project overview and summary of experimental results

Section Summary

This Section (Part I) provides a general overview of the sampling and experimental work that was undertaken for this study. Throughout the study, mixed waste organic outputs were sampled from two facilities in NSW (Facility A and B). Sampling was conducted over five sampling events (SE1-SE5) that covered a range of climatic seasons. The sampling procedure involved collecting grab samples from the facilities and then producing composite samples by sub-sampling the grab samples. Two methods were then used to generate leachates from selected composite samples. This included batch extractions, which used a constant solid to liquid ratio (1:20) and column leachates, which generated four subsequent leachate fractions (F1-F4).

Both the solids and leachates were subject to a range of chemical analysis including, general chemical parameters, macronutrients, inorganic elements, major anions and sulfide, PAHs, phenolic compounds, chlorobenzene and nitrobenzene compounds, plasticisers, pesticides, polychlorinated biphenyls (PCBs), alkylphenols, bisphenol A (BPA), organotins, polybrominated flame retardants, polyfluorinated compounds (PFCs) and asbestos. In all of the solid samples analysed, chlorobenzene and nitrobenzene compounds, PCBs, PFCs and asbestos were below the LOQ. Chemicals from the remaining groups were detected in both the solid material and the leachates throughout the study. The only exceptions to this were: the PAH compounds and alkylphenols that were only detected in the solid material and not in the leachates; and BPA which only underwent some preliminary analysis in the leachates during SE1-SE2 (subsequent analysis was not conducted as the method was not validated). The frequencies of detection and concentrations varied considerably for the different chemicals.

Toxicity testing was conducted on the batch extractions and the F1-F4 leachate fractions during SE4 and SE5. This testing was conducted with three test species, the cladoceran *Ceriodaphnia dubia*, the bacteria *Vibrio fischeri* and the microalga *Pseudokirchneriella subcapitata*. The leachates were found to be toxic to the three test species. The F1 fraction was consistently the most toxic with <1 to 22% leachate samples causing a 50% reduction in a test response (EC50). The toxicity became less pronounced with each subsequent column fraction, which was consistent with the chemical profiles of the samples. The toxicity of the batch extraction samples were roughly consistent with the F2 fraction from the column leachates.

Finally, toxicity identification evaluation (TIE) was also conducted on the F1 samples from the column leachates. This procedure aims to identify specific toxicants or groups of toxicants contributing to the overall toxicity of a sample. In this study, the TIE demonstrated that ammonia, sulfide and major ions (measured as EC) were contributing to the overall toxicity of the leachates.

1 Project introduction

Alternative waste treatment facilities process domestic and commercial waste streams to produce mixed waste organic outputs (MWOO). The AWT process is a mechanical and biological process that aims to produce an organic material that is used as a soil amendment and therefore divert waste away from landfill. As municipal waste can be highly variable and contain a range of non-degradable materials (e.g. household appliances, old furniture, batteries, light globes and household chemicals such as paints and pesticides), the challenge faced by facilities is to produce a final product that provides environmental benefits and poses minimal risk of harm to the environment and human health. The process initially involves the removal of hazardous materials (such as gas cylinders and car batteries), recyclables, and non-degradable items from the municipal waste stream. The remaining organic fraction is then biologically stabilised. The resulting product tends to have a relatively high nutrient concentration and high organic carbon content and can be used through land application in NSW as a supplement for inorganic fertilisers. Examples of the waste before and after sorting and processing are shown in Figure 2.

(a)

(b)

Figure 2: Municipal solid waste (a) prior to sorting/processing and (b) after sorting/processing and ready for use

Currently supply and quality of MWOO in NSW is regulated under a Resource Recovery Order (RRO) and the land application of MWOO is regulated under a Resource Recovery Exemption (RRE). The RRO specifies thresholds for a number of chemical and physical attributes in the material, which are currently based on limited scientific information. Other than the chemicals that require testing under the RRO, there is also currently limited information available on the nature and chemical composition of MWOO, making it difficult to evaluate the potential risks that may be posed to the environment and human health following land application. The objectives of this study were to determine the composition of chemicals in MWOO solid material and determine the natural variability in the material over a range of sampling events spanning different climatic seasons. In addition, the project aimed to determine the potential for contaminants to be mobilised into leachates generated from MWOO and to determine the toxicity of the leachates. The final objective of this project was to use the data collected throughout the study to highlight priority chemicals through a hazard assessment process that can be the focus of future work assessing the potential risks of MWOO to the environment and human health following land application. This project is a component of a larger MWOO research program. All of the projects in the program:

- Project 1 – Assessing the impacts of physical contaminants in MWOO on the soil environment
- Project 2 – Large scale field trial assessing the impacts of MWOO using field based crop/soil responses
- Project 3 – Assessing the toxicity of MWOO leachates (this project)
- Project 4 – Assessing the behaviour of MWOO on different NSW soils.

The outcomes from this project and the research program will assist in the review of the RRO and RRE for the supply and land application of MWOO.

2 Project experimental design and leachate generation

2.1 Sampling design and collection

Throughout the project, MWOO samples were collected from two AWT facilities in NSW (Facility A and Facility B). There were several differences in the treatment processes between the facilities, which are outlined in the 2014 Progress Report. Samples were collected from each facility during five sampling events. These were conducted to cover different climatic seasons which allowed for any differences in feedstock material due to seasonal social habits to be accounted for. The sampling events were:

Sampling event 1 (SE1) – November 2011
Sampling event 2 (SE2) – August 2012
Sampling event 3 (SE3) – March 2013
Sampling event 4 (SE4) – July 2013
Sampling event 5 (SE5) – January 2014

Each of the sampling events spanned several weeks and multiple composite and grab samples were collected. At each sampling event, material that had most recently completed the treatment process was sampled. This material was therefore representative of material ready to leave the site for use under the RRO. During SE1, samples were collected weekly over 7 weeks (i.e. 7 sampling rounds). Note that due to bad weather and restricted access to the site, one sampling round at Facility B was not completed. During each sampling round, 8 grab samples were collected at each of the facilities to be stored individually. A subsample was also removed from each of the grab samples to produce a composite sample for that round. The chemical analysis of the SE1 samples was focussed on the composite samples from each sampling round as well as the grab samples from the first sampling round.

Based on an assessment of the variability in the data from SE1, the sampling design was modified for SE2-SE5. The modified design still included collection of both grab and composite samples, however, it was conducted over four sampling rounds spaced two weeks apart (Figure 3). During each sampling round, five grab samples were collected. A subsample was removed from each of the grab samples to produce a composite sample for each sampling round. The majority of chemical analysis for the SE2-SE5 samples (e.g. metals, polycyclic aromatic hydrocarbons, phenols, chlorobenzenes, nitrobenzene and some of the phthalate compounds) was focussed on the composite samples, all of the grab samples from round 1 and one randomly selected grab sample from each of rounds 2-4 (Figure 3). Depending on the chemical analyses, in some cases only the composite samples were analysed. This sampling design was used to allow any short-term and long-term variability in chemical concentrations in the material to be captured in the data collected.

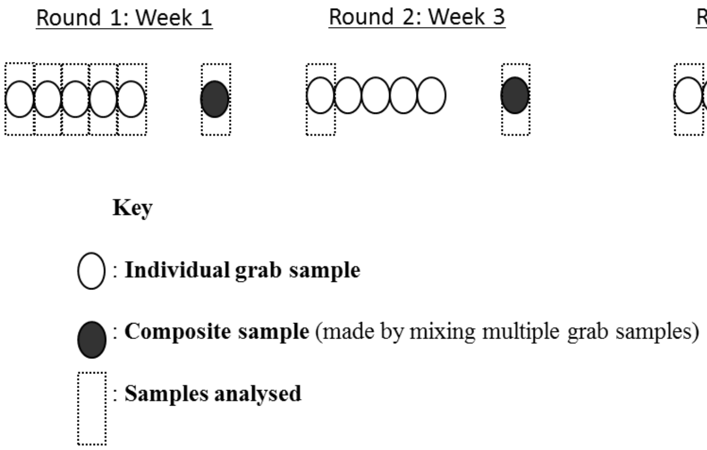

Figure 3: Summary of sampling design for sampling events 2-5. Note that grab samples were only analysed for selected groups of chemicals.

2.2 Generation of leachates from solid material

To investigate the potential for chemicals to be mobilised from MWOO, two methods were used to generate leachate samples. These included batch extractions and continuous column leachates.

2.2.1 Batch extractions

Traditional batch extractions of the MWOO material were conducted based on US EPA Method 1311 (USEPA, 1992). This is a standard method that gives an indication of the solid solution partitoining of chemicals at one solid to liquid ratio. The results from this extraction will be used in the following section of this report to calcualte solid solution partitioning coefficients (Kd). The method involved adding deionised water to the solid samples at a solid to liquid ratio of 1:20 (50 g material (wet weight) and 1L liquid). Following addition of the extraction liquid the samples were placed in an end-over-end shaker and rotated at 30 ± 2 rpm for 18 hours. The samples were then filtered to 0.8 µm prior to chemical analysis (additional filtering was done for some of the analyses, see details below for individual chemical groups).

During SE1, the effect of extraction liquid pH (pH 4.0, neutral and pH 9.2) and extraction temperature (25°C and 35°C) was investigated (see 2013 Progress Report). This work showed that there was minimal effect of pH and temperature on the resulting chemical composition of the extracts. Based on this preliminary work, deionised water (neutral) was used and all extractions were conducted at room temperature (23°C ± 2).

2.2.2 Continuous column leachates

Continuous column leachates were generated based on the procedure outlined in the German Standard Method – Leaching of Solid Material (DIN, 2009). This procedure provides more information about the long term leaching of chemicals from the material, for example, if chemicals continue to leach over time or if following the initial release of a highly mobile fraction, the remaining fraction in the material is immobile. The method involved packing approximately 300-310 g (wet weight) of solid MWOO material into a glass column (Figure 4). Sand was packed at the top and bottom of the material within the glass column to ensure that it was entirely packed. Glass wool was also placed at either end of the column to aid with filtration of the leachate solution. After the column was packed, it was inverted and placed on a column apparatus (Figure 4).

The optimal parameters, such as flow rate, particle density and pore volume were determined prior to commencing leaching. Before leachate was generated through the column, deionised water was pumped into the column from the base of the column in an upward direction through the sample to saturate the material in the column. The pump was then stopped and the saturated column was allowed to equilibrate for 2 hours. Following the equilibration period, deionised water was pumped through the base of the column and leachate was generated through the top of the column. The columns were continuously leached for 7 days.

Figure 4: Column unit and pump used to generate MWOO column leachates

During the project, two different methods were used to collect leachates from the column. These were the collection of small ‘snapshot’ samples (approximately 300 mL) and the collection of larger sequential whole ‘fractions’. The small snapshot samples were collected during SE1-SE3 as this allowed for more samples to be collected providing preliminary chemical data on the types of chemicals that were leached from the material, the duration of chemical leaching and the concentrations mobilised. The results from the column snapshots have been presented in the 2013 Progress Report. As this was preliminary work, the results will not be presented in this report.

During SE4 and SE5 large leachate fractions were collected from the column. This method provided an understanding of the mobility of chemicals based on specific solid to liquid ratios. It also ensured that sufficient leachate was generated to allow ecotoxicological testing to be conducted on the same samples that had undergone chemical analysis. The flow rate was approximately 1.4 mL/min and the duration and volumes collected are summarised in Table 2. The leachate fractions were filtered through a 0.8 µm filter prior to analysis.

Table 2: Leachate fraction collection times and volumes of leachate collected

Fraction	Time (hrs)	Approx. volume of leachate (L)	Approx. cumulative volume of leachate (L)
F1	0-18	1.5	1.5
F2	18-35	1.5	3.0
F3	35-70	3.0	6.0
F4	70-163	8.0	14

3 Chemical analysis of solid material and leachates

Both the solid material and leachates (batch extractions and column leachates) were subject to extensive chemical analysis. This was conducted on a broad range of general parameters and specific chemicals. A full list of all the parameters and chemicals analysed and a summary of the results for each facility is provided in Appendix A. Chemical analyses were conducted in National Association of Testing Authorities (NATA) accredited laboratories following the quality control/quality assurance (QA/QC) requirements of ISO/IEC 17025:2005

In general, the chemicals analysed in the solids and the leachates were the same. There were some exceptions to this, dependant on the availability of analytical techniques. The selection of chemicals for analysis in this study was based on knowledge of the waste stream, availability of analytical methods, current literature and project budget. Refer to the '*Mixed Waste Organic Outputs: Contaminants, Land Application and Environmental Effects, A Research Framework*' (Wilson et al., 2014) for an extensive summary of chemicals that may be present in the material.

3.1 General chemical parameters

The general chemical parameters that were measured on the MWOO solid material and the leachates included pH, EC, moisture (solids only), total organic carbon (TOC) (solids only) and dissolved organic carbon (DOC) (SE5 leachates only). None of these parameters are required to be tested under the RRO. The pH and EC were measured in the samples using a pH probe and ion selective electrode, respectively (analysis was conducted on the solids following a 1:5 solid to liquid extraction with water). Sample pH and EC were measured on all column leachate fractions (F1 – F4) and the batch extractions from both facilities during SE5 only. The moisture content of each of the solid samples was measured by drying the sample at 105°C. To measure TOC and DOC in the samples, the organic matter was oxidised and the organic carbon content was determined by spectrophotometry.

Analysis of the solid material indicated that the pH ranged from 5.7 to 8.7 (average 6.7), EC ranged from 5.2 to 14 dS/m (average 8.4 dS/m), moisture ranged from 22 to 53% (average 34%) and TOC ranged from 19 to 45% (average 34%). Overall, there was no difference observed between the two facilities in terms of these parameters.

In the column leachates, the EC of the F1 fraction was approximately 11 dS/m and this decreased considerably with each subsequent fraction (F2-F4) (Figure 5). In the F4 fraction the EC was approximately 0.5 dS/m. This indicates that the salts present in the material were quickly leached and removed from the system with the initial infiltration of water. The pH showed the opposite trend, whereby pH increased with each subsequent fraction (from 6.8 to 7.7), which is likely also to be due to the loss of highly mobile chemicals in the initial fractions (Figure 5). In the batch extractions, the average pH was 6.9 and the average EC was 2.6 dS/m.

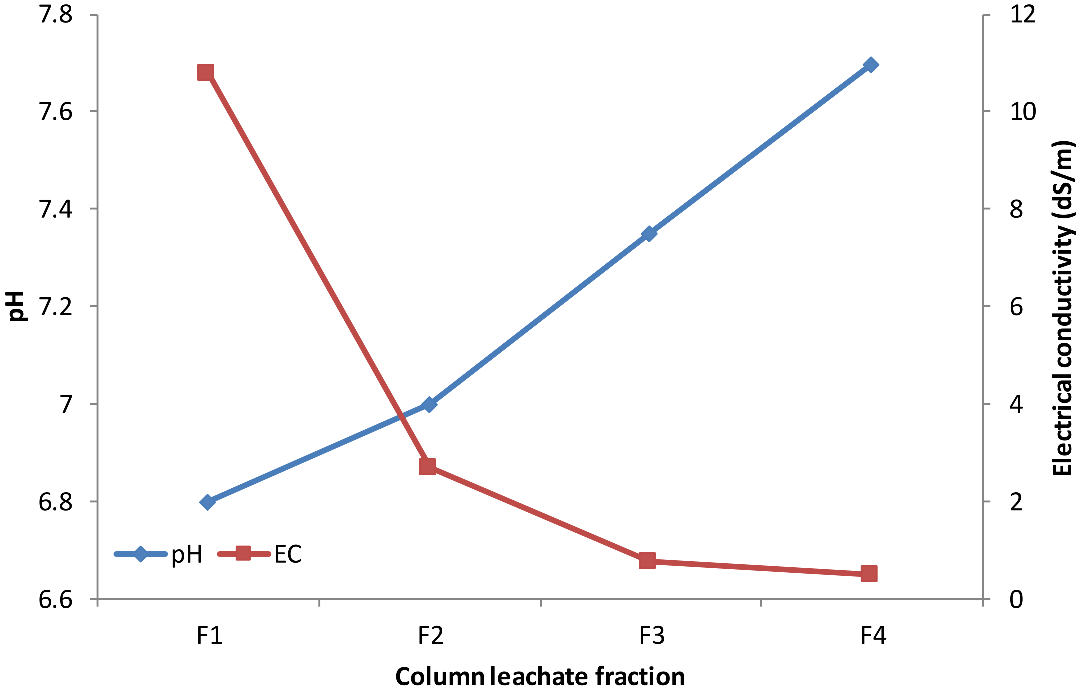

Figure 5: Electrical conductivity (EC) and pH of the leachate fractions from the continuous column leachates

3.2 Macronutrients

One of the primary benefits of land applying MWOO is that it can contain high concentrations of nutrients, therefore it may be used as a supplement for inorganic fertilisers. Two of the main macronutrients of importance in crop development are nitrogen and phosphorus. The plant availability of these nutrients depends on the form that they are present in, for example, organic or inorganic. Although nutrients are essential for healthy crop development, excess nutrients may pose a risk to nearby groundwater and surface water. There are no requirements in the current exemption for testing and analysis of nutrients. In this study, total Kjeldahl nitrogen (TKN) and total phosphorus were measured in the solid material. TKN provides a measure of the sum of organic N, ammonia (NH_3) and ammonium (NH_4^+) in a sample. The batch extractions and leachates (F1 to F4) were analysed for free forms of nitrogen and phosphorus, including:

total ammonia-N ($NH_3 + NH_4^+$), NOx-N ($NO_2^- + NO_3^-$) and free reactive phosphorus (FRP) (e.g. PO_4^{3-}), following additional filtering to 0.45 µm. Nutrient analyses were conducted using a colorimetric flow injection analyser. In addition to the free nutrients, total phosphorus was also measured as part of the inorganic elements analysis (Section 3.3).

In the solid material the concentrations of TKN were found to range from 8800 to 26000 mg/kg (average 17000 mg/kg) and total phosphorus concentrations ranged from 3100 to 6800 mg/kg (average 4600 mg/kg). There was minimal difference between the two facilities in terms of TKN and total phosphorus concentrations.

In the batch extractions and leachate samples, the most dominant forms of free nutrients were found to be total ammonia-N and FRP. Although NOx-N was found to be above the LOQ in some of the batch extraction and leachate samples (ranging from 0.3 to 22 mg/L), in the vast majority of samples NOx-N was found to be below the LOQ of 0.02 mg/L. The free nutrients in the leachates were dominated by total ammonia, with concentrations averaging 350 mg N/L in the F1 fraction. Similar to the EC trend, the concentrations of total ammonia decreased considerably with each subsequent leachate fraction (Figure 6). In contrast, the concentrations of FRP were considerably lower than total ammonia, with an average concentration in the F1 fraction of 4.5 mg/L. The concentrations of FRP in the subsequent fractions did not decrease by the same magnitude as the ammonia concentrations and the variability in the concentrations was considerably greater (Figure 6).

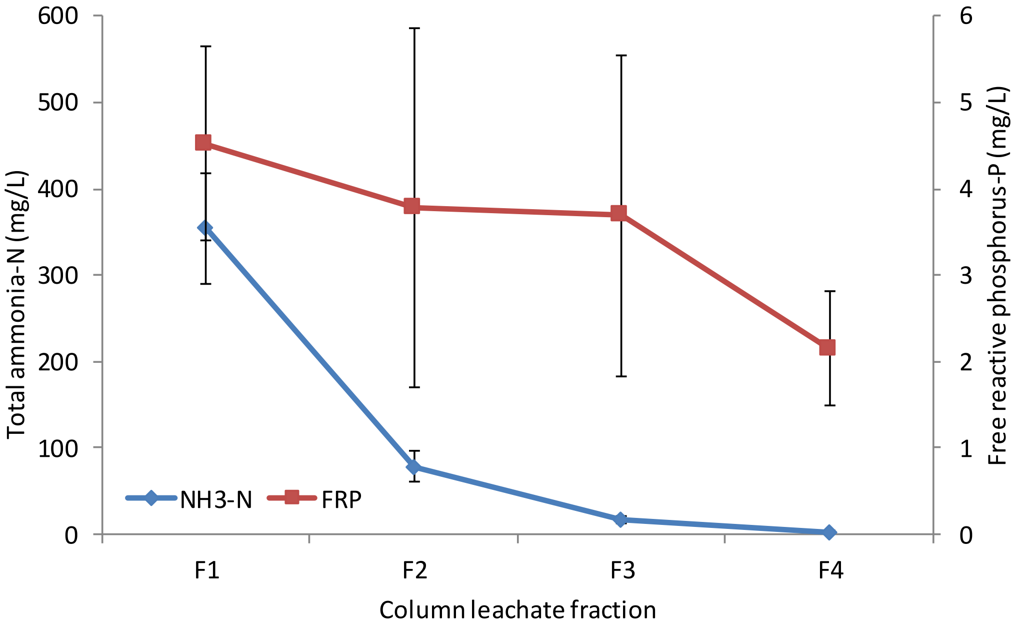

Figure 6: Total ammonia (NH_3-N) and free reactive phosphorus (FRP) in the leachate fractions from the continuous column leachates. Error bars indicate one standard error.

3.3 Inorganic elements

Due to the diverse range of feedstock materials into AWT facilities, there are likely to be a range of inorganic elements in the final product. The inorganic elements that were analysed in the MWOO solid material, the batch extractions and leachates can be summarised under three general groups: major cations, metals, and metalloids (Table 3). For the remainder of this report, the term metals will refer to both metals and metalloids. The analysis of inorganic elements was conducted using ion-coupled plasma atomic emission spectroscopy. Mercury was analysed using cold vapour atomic absorbance spectroscopy. For the solid material, the samples were digested in acid prior to analysis and all leachate samples were filtered to 0.45 µm.

Table 3: List of inorganic elements measured in the MWOO solid material and leachate

Major Cations	Metals	Metalloids
Calcium (Ca)	Aluminium (Al)	Antimony (Sb)
Magnesium (Mg)	Barium (Ba)	Arsenic (As)
Potassium (K)	Beryllium (Be)	Boron (B)
Sodium (Na)	Cadmium (Cd)	
	Chromium (Cr)	
	Cobalt (Co)	
	Copper (Cu)	
	Iron (Fe)	
	Lead (Pb)	
	Lithium (Li)	
	Manganese (Mn)	
	Mercury (Hg)	
	Molybdenum (Mo)	
	Nickel (Ni)	
	Selenium (Se)	
	Silver (Ag)	
	Strontium (Sr)	
	Sulfur (S)	
	Thallium (Tl)	
	Tin (Sn)	
	Titanium (Ti)	
	Vanadium (V)	
	Zinc (Zn)	

The RRO currently provides threshold concentrations for a range of metals, including, mercury, cadmium, lead, arsenic, chromium, copper, nickel, selenium and zinc. The RRO also requires testing and analysis for a range of other metals but doesn't contain threshold concentrations. These include, antimony, beryllium, boron, cobalt, manganese, molybdenum, tin and vanadium.

The major cations, calcium, sodium, magnesium and potassium were measured in high concentrations in all of the solid MWOO samples. This result is consistent with the high EC measurements that were observed from the material (Section 3.1). Calcium was the most dominant cation with average concentrations of approximately 30 g/kg (ranging from 17 to 42 g/kg). Magnesium was the least dominant of the major cations, with an average concentration of 2.3 g/kg (ranging from 1.5 to 4.5 g/kg). The average concentrations of major cations did not vary greatly between the two facilities.

As expected, the leaching profile of the major cations showed a similar trend to that observed for EC, whereby there was a sharp decrease in concentration following the F1 fraction (refer to 2014 Progress Report for more detail). The concentrations of sodium, calcium and magnesium in each sample were also used to calculate the sodium adsorption ratio (SAR) of the leachates to give an indication of potential soil sodicity issues. In the F1 fraction, the SAR was found to range from 5.8 to 14 and in the batch extractions it ranged from 2.9 to 5.5.

There were 26 metals analysed in the solid material. The majority of these were detected in 100% of the samples, including, aluminium, arsenic, barium, chromium, cobalt, copper, iron, lead, manganese, nickel, strontium, sulfur, tin, titanium, vanadium and zinc. Several elements were detected in some samples but less than 100%, including, antimony, beryllium, boron, cadmium, lithium, mercury, molybdenum and silver. Finally, selenium and thallium were not found above their corresponding LOQ in any of the samples tested.

Overall there were some differences observed in average metal concentrations between the two facilities. However, there was no general trend where one facility showed consistently higher concentrations than the other. The greatest differences in metal concentrations between the two facilities were for copper and nickel, where Facility A had average concentrations for both metals that were approximately 5-times higher than the other facility.

Of the metals that have threshold concentrations in the exemption, mercury, arsenic and selenium were found to not exceed the maximum allowable concentration in all of the samples. In contrast, cadmium, lead, chromium, copper, nickel and zinc were found to exceed the corresponding threshold concentration in at least 2 samples. The greatest exceedance past the threshold concentration was observed for nickel where the maximum measured concentration was 2900 mg/kg, which is approximately 50-times higher than the threshold concentration of 60 mg/kg. The highest proportion of exceedances was observed for lead, which was found to exceed the threshold of 250 mg/kg (for plantation forestry use, non-contact agricultural use and broad acre agricultural use) in approximately 25% of the samples. There are, however, two thresholds for lead depending on the final use of the material and only 4% of the samples were found to exceed the threshold for mine site use of 420 mg/kg.

All of the metals that were detected in 100% of the solid samples were detected frequently in the batch extractions and column leachates. Half of these metals (aluminium, copper, iron, manganese, nickel, strontium, sulfur and zinc) were detected in all four of the leachate fractions (F1 to F4), however, a similar trend was observed to that outlined above where the concentrations decreased considerably in each subsequent fraction. The remaining chemicals that were detected in 100% of the solid samples were detected in the F1 to F3 fractions, with the exception of tin, which was only detected in F1 and F2. These results indicate that there is the possibility of ongoing leaching of many of these metals from the material, although the total concentration will decrease over time.

3.4 Major anions and sulfide

Major anions (chloride and sulfate) were measured in selected batch extraction and column leachate samples throughout the project. This analysis was conducted using ion exchange chromatography following the sampling being filtered to 0.45 µm. There was no direct measurement of these major anions in the solid material. Chloride and sulfate were detected in all batch extraction and column leachate samples, with the exception that chloride was below the LOQ in the F4 fraction of the column leachates. In the batch extractions, the concentrations of chloride and sulfate ranged from 170 to 270 mg/L and 76 to 180 mg/L, respectively. As expected, the concentrations of these anions were considerably higher in the F1 fraction of the column leachates, ranging from 740 to 1100 mg/L and 240 to 790 mg/L, respectively.

During SE5, measurements of total sulfide (the sum of concentrations of un-ionised H_2S, bisulfide ions HS^-, sulfide ions S^{2-} and acid soluble metallic sulfides) were incorporated into the study, as this was considered likely to be contributing to the toxicity of the leachates (from the TIE). This measurement was done on the F1 fractions from the column leachate samples only. Analysis was conducted using a colorimetric assay and concentrations of total sulfide-S in the F1 fraction were found to ranged <0.1 to 0.29 mg/L.

3.5 Polycyclic aromatic hydrocarbons

Polycyclic aromatic hydrocarbons are organic compounds composed of multiple aromatic rings and contain only carbon and hydrogen. PAHs can occur naturally in the environment and can also be man-made. They are mainly formed through the incomplete combustion of organic materials, however, some PAHs are also used in the production of consumer products, for example, dyes, plastics and pesticides. PAHs have low water solubility and are highly lipophilic, meaning that they have an affinity to bind strongly to solid particles (e.g. soil). The primary human health risk associated with exposure to PAHs is that some compounds exert mutagenic and carcinogenic activity. The RRO requires that testing and analysis be undertaken for PAHs, however, there are no threshold values.

Although there is a large number of PAH compounds that have been identified, the chemical analysis in this study focussed on the USEPA 16 prioritised PAH compounds. These include: naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benzo[a]anthracene, chysene, benzo[b]fluoranthene, benzo[k]fluoranthene, benzo[a]pyrene, dibenz[ah]anthracene, benzo[ghi]perylene and indeno[1,2,3-cd]pyrene. It should be noted that eight of these compounds are classed as either human carcinogens, probable human carcinogens or possible human carcinogens, including: benzo[a]anthracene, benzo[a]pyrene, benzo[b]fluoranthene, benzo[k]fluoranthene, benzo[ghi]perylene[1], chrysene, dibenz[ah]anthracene and indeno[1,2,3-cd]pyrene.

To measure PAHs in the solids and leachates, the samples were initially extracted with solvent. Following this, they were analysed using gas chromatography-mass spectrometry (GC-MS).

Of the 16 priority PAH compounds only six compounds (acenaphthene, fluoranthene, fluorene, naphthalene, phenanthrene and pyrene) were detected in any of the solid samples. There was no difference observed between the two facilities in terms of the detection frequency of these compounds. The remaining compounds were below the LOQ of 0.13 mg/kg in all of the samples. The most frequently detected PAHs were naphthalene and phenanthrene, which were detected in approximately 70% and 63% of the samples respectively. No carcinogenic PAHs were detected in any of the solid samples tested. Across the two facilities, the average concentration of total PAHs (sum of 16 priority compounds) was approximately 1 mg/kg, with a maximum concentration of 5.2 mg/kg.

There were no PAH compounds detected in any of the batch extraction or leachate samples. This is expected as these compounds are highly hydrophobic and therefore will partition strongly to the organic matter in the MWOO.

3.6 Phenolic compounds

A broad range of phenolic compounds, including phenol, methylphenols, chlorophenols and nitrophenols were analysed for in this study. There are a range of uses for phenols, including their use in disinfectants, biocides, preservatives, dyes, pesticides and medical/industrial chemicals. They can also be produced through the degradation of organic matter (e.g. plant material) or degradation of various man-made organic chemicals. From these sources, phenolic compounds tend to be found in various industrial and

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[1] Benzo[ghi]perylene is included due to positive findings in genotoxicity studies (WHO 1998). Note that there is insufficient data available to determine carcinogenicity.

municipal wastes. To measure phenolic compounds in the solids and leachates, the samples were initially extracted with solvent. Following this, they were analysed using GC-MS. There is no requirement for testing and analysis of phenolic compounds in the RRO.

Phenol and 3+4-methylphenol were the only phenolic compounds measured above their corresponding LOQ in the solid material. Phenol was detected in close to 100% of the samples at concentrations up to 98 mg/kg. In contrast 3+4-methylphenol was detected in approximately 50% of the samples at concentrations up to 71 mg/kg. The average concentrations of phenol were very similar between the two facilities, however, the average concentrations of 3+4-methylphenol was approximately 6-times higher at Facility B compared to Facility A.

Phenol and 3+4-methylphenol were detected in approximately 70% of the batch extractions and column leachate samples. The concentrations of phenol were found to range up to 2.3 mg/L in the F1 fractions, whereas, the highest concentration of 3+4-methylphenol in the same fraction was 0.4 mg/L.

3.7 Chlorobenzene and nitrobenzene compounds

A range of chlorobenzenes and nitrobenzenes, including, hexachlorobenzene, pentachlorobenzene, nitrobenzene and pentachloronitrobenzene were analysed in this study. These compounds are used in a range of industrial applications, for example, in the production of dyes, herbicides and pharmaceuticals, as well as their use as lubricants and heat transfer medium. There are no requirements in the RRO for testing and analysis of chlorobenzene or nitrobenzene compounds. To measure chlorobenzene and nitrobenzene compounds in the solids and leachates, the samples were initially extracted with solvent. Following this, they were analysed using GC-MS. All chlorobenzene and nitrobenzene compounds that were analysed for in the solids and leachates were found to be below the LOQ. Based on this, these compounds will not be discussed further in this report.

3.8 Plasticisers

Plasticisers are additives that are used to increase the plasticity or fluidity of a material and are primarily used in plastics. The most commonly used plasticisers are phthalates. These compounds can be easily leached out of plastic products because many are not chemically bound to the plastic matrix. The full list of phthalates that may be used in products is extensive, however, a subset of compounds was selected for this study that was considered to be sufficient to provide an indication of the presence of phthalates in

MWOO and MWOO leachates. The suite of phthalate compounds included dibutyl phthalate, benzyl butyl phthalate, bis-2-ethylhexyl phthalate (DEHP), dioctyl phthalate, diethyl phthalate and dimethyl phthalate. Of these compounds, DEHP is generally one of the most widely used phthalates in consumer products. The primary concern relating to human and environmental exposures to phthalates is that they are considered to be endocrine disrupting compounds, meaning they may have an adverse effect on reproduction and development. It is important to note that limited human studies are available relating to the effects of phthalates and in most cases effects observed in rats are considered potentially relevant to humans (USEPA, 2012). There is a requirement in the RRO for testing and analysis of DEHP and dibutyl phthalate, however, there are currently no threshold concentrations.

Due to concerns relating to the toxicity of phthalate compounds, alternative compounds are now being used in some products. One such compound that is being used as a substitute for DEHP is bis-2-ethylhexyl adipate (DEHA). Due to this, analysis of DEHA was also included in this study.

The analysis of phthalates in the solid MWOO and the batch extractions and leachates was conducted by initially extracting the samples with solvent. The extracts were then analysed using GC-MS.

DEHP and DEHA were the most frequently detected plasticisers in the solid material. These compounds were detected in close to 100% of the samples tested up to concentrations of 2600 mg/kg and 52 mg/kg, respectively. The average concentrations of both of these compounds were approximately 2.5-times higher in the material from Facility A compared to Facility B. The remaining plasticiser compounds showed very infrequent detection, with each compounds detection frequency ranging from 0 to 15%.

In the batch extractions and column leachates, the plasticiser compounds were detected very infrequently, normally only 1-2 detects for each compound. This is likely due to the strong partitioning of these compounds to organic carbon in the solid material and low water solubility (e.g. DEHP has a log organic carbon-water partitioning coefficient (log Koc) of approximately 5, indicating that it will partitioning strongly to organic carbon rather than into water). The compound detected at the highest concentration was DEHP at 0.04 mg/L. It should be noted that due to the complexity of the leachate matrix, some of the quantification limits were high (refer to Appendix A).

3.9 Pesticides

Pesticides are commonly used commercially and residentially, therefore, a range of possible inputs into waste processing facilities are likely. In the RRO there are requirements to test for a range of pesticides. In this study, approximately 100 pesticide and herbicide compounds were analysed for in the solids and the leachates. For this analysis, an initial extraction with solvent was conducted. Following this, depending on the compounds, analysis was either conducted using GC-MS or high performance liquid chromatography with MS (HPLC-MS).

The vast majority of pesticide compounds were below the corresponding LOQ in all of the solid samples tested (refer to Appendix A for LOQ concentrations). The compounds that were detected in at least one sample included atrazine, bifenthrin, endosulfan I, fipronil, gamma chlordane, metalaxyl, prometryn, thiabendazole, trans permethrin, 2,4,5-T (2,4,5-trichlorophenoxyacetic acid), 2,4-D (2,4-dichlorophenoxyacetic acid), dicamba, MCPA (2-methyl-4-chlorophenoxyacetic acid) and MCPP (methylchlorophenoxypropionic acid). In many of these cases, the detection frequency was very low (i.e. < 10%) (refer to Appendix A for all summary data). Of these detected compounds, thiabendazole, dicamba, MCPA and MCPP were the most frequently detected and were found in greater than 50% of the solid samples tested. Of these compounds, MCPA, which is a phenoxy-acid herbicide used to control broadleaf weeds, was detected at the highest concentrations, up to 1.8 mg/kg. There was only a slight difference between the two facilities in terms of average concentrations of these four compounds, however, Facility A consistently showed higher concentrations than the other Facility by 1.3- 1.6-times.

In the batch extractions and column leachates, the suite of pesticides was slightly different to that analysed for in the solid material, for example, thiabendazole was not measured in the batch extraction and column leachate samples. This was due to a water method for analysis not being available for this compound. In the batch extractions and leachate samples, the most commonly detected pesticides were dicamba (60%), MCPA (76%) and MCPP (38%). This result is consistent with these compounds being found at the highest concentrations in the solid material.

3.10 Polychlorinated biphenyls

The inclusion of polychlorinated biphenyls (PCBs) into the study was based primarily on their inclusion and restriction in the MWOO RRO. A screen for PCB aroclors was conducted on all of the solid samples and a lower detection PCB analysis was conducted on selected composite samples. In all cases, the concentrations of all PCB aroclors were below the quantification limit (refer to Appendix A for range of quantification limits). Due to this, PCBs were considered to be of low likelihood to occur in MWOO and are not be discussed further in this report.

3.11 Alkylphenols

Alkylphenols are degradation products from non-ionic alkylphenol ethoxylate surfactant compounds that are present in a range of consumer products, including, domestic detergent, pesticide formulations and industrial products (Ying et al., 2002). The most commonly used alkylphenol ethoxylate compounds are nonylphenol ethoxylates and octylphenol exothylates. These compounds are known to readily degrade under aerobic conditions to their more persistent metabolite compounds, including 4-nonylphenol (4NP), 4-tert-octylphenol (4tOP) and 4-octylphenol (4OP) (McAvoy et al., 2002, Ying and Kookana, 2005, Press-Kristensen et al., 2008). The most significant concern relating to the presence of these metabolites in the environment is that they are known to be more toxic than the parent compounds and they have the ability to mimic natural hormones by interacting with estrogen receptors (Soto et al., 1991, Routledge and Sumpter, 1996, Renner, 1997). There is currently no requirement in the RRO for testing and analysis of alkylphenols.

The compound 4tOP was below the LOQ in all of the solid samples, whereas, 4OP was detected in about 40% of the samples. In contrast, 4NP was measured at concentrations above the LOQ in 100% of the solid samples tested at concentrations up to 5.7 mg/kg. There was minimal difference observed in the average concentrations of 4NP between the two facilities.

In the batch extractions and column leachates, these compounds were below the LOQ in all samples. There was only a limited number of batch extractions and column leachates analysed for these compounds, therefore, additional testing of samples in future studies may be recommended.

3.12 Bisphenol A

Bisphenol A is a compound that is widely used in manufacturing of polycarbonate plastics and epoxy resin. It is ubiquitous in the environment due to its use in a broad range of products, including food and beverage packaging, adhesives, building materials, electronic components and paper coatings (Flint et al., 2012). This compound can also be formed as a breakdown product of the flame retardant tetrabromobisphenol A (Haynes et al., 2009). The concerns surrounding BPA are predominately due to its ability to interfere with estrogen receptors. There is currently no requirement in the RRO for testing and analysis of BPA. In this study, BPA analysis was conducted using HPLC-MS following solvent extraction.

Bisphenol A was detected in 100% of the solid samples tested. The concentrations ranged from 4 to 100 mg/kg with an average concentration of 26 mg/kg. The average concentration of BPA was approximately two-times higher in material from Facility B compared to Facility A. Interestingly, this was not the same facility that showed higher concentrations of the plasticisers DEHP and DEHA, suggesting that plastics may not be the primary source of BPA contamination in the material.

This compound was only analysed for in a small number of the leachate samples (batch and column) during SE1 and SE2. These results showed concentrations that ranged from <0.03 to 0.26 mg/L depending on the sample type tested. This is considered preliminary data as leachate samples were not tested for this compound at later stages of the project as the analytical method had not been accredited. These results do suggest that some BPA is mobilised in the leachates, therefore, it would be recommended to undertake some additional testing and analysis of this compound to better understand this and the associated risks.

3.13 Organotins

Organotins have been widely used in a range of industrial and agricultural applications, including polyvinyl chloride stabilisers, fungicides, bactericides, insecticides, industrial catalysts and wood preservatives (Hoch, 2001). Historically, tributyltin (TBT) has been used as an antifouling agent for ship hulls and generally as a wood preservative, however, its use has ceased internationally due to high toxicity to aquatic organisms. TBT has also been identified as an endocrine disrupting compound. In addition, organotins are known to be neurotoxic, carcinogenic and immunotoxic, with TBT considered the most toxic. The degradation of organotins is through the sequential removal of the alkyl groups attached to the tin. Hence, tributyltin degrades to dibutyltin (DBT) and then monobutyltin (MBT). The end product of organotin degradation is inorganic tin. The RRO requires testing and analysis of monobutyl tin in the material but it does not include a threshold concentration for this compound. There are currently no testing and analysis requirements for dibutyl tin and monobutyl tin in the RRO. In this study, analysis of the samples for organotins was conducted using gas chromatography atomic fluorescence spectrometry following sample extraction.

The organotin compounds were measured on a limited set of solid samples (six samples in total). In these samples, MBT and DBT were detected at a frequency of 100%. The distribution of concentrations of these two compounds was similar, with MBT having concentrations that ranged from 1.7 to 37 µg/kg (average concentration 12 µg/kg) and DBT concentrations ranging from 2.2 to 28 µg/kg (average concentration 12 µg/kg). The average concentrations of both these compounds were approximately two-times higher at Facility A compared to Facility B. TBT was detected at a much lower frequency of 50% in the solid material, which is to be expected due to the limited use of this compound and sequential debutylation of TBT to DBT and MBT. The concentrations of this compound were also considerably lower, ranging from < LOQ to 5.8 µg/kg (average concentration 1.1 µg/kg, considering only data that were above the LOQ).

The organotin compounds were only measured in selected batch extractions during SE1-SE3. MBT was the only compound that was measured above the LOQ in two of the six samples tested. The concentrations that were above the LOQ ranged from 5 to 8 µg/L. In all other cases, the concentrations were below the LOQ, which ranged from < 2 to < 10 µg/L.

3.14 Polybrominated flame retardants

Flame retardants are incorporated into a wide range of products to reduce their fire risk, for example, building materials, textiles, furnishings, plastics and electrical components. There are a range of flame retardants that are used in products but the group that receives most interest are the polybrominated diphenyl ethers (PBDEs), due to their potential environmental and human health risks.

The chemical structure of PBDEs consists of between 1 and 10 bromine atoms per molecule (Figure 7), resulting in 209 unique congeners. The most commonly found PBDEs are the tri-BDEs to deca-BDE (note that all levels of bromination have multiple congeners, which the exception of deca-BDE for which there is only one congener possible that is fully brominated). There are three commercial formulations of PBDEs, with each one named based on the prominent homologue in the mixture i.e penta-BDE, octa-BDE and deca-BDE. Despite the commercial names, these PBDE mixtures also contain congeners with different numbers of bromine atoms, for example, penta-BDE contains mainly penta-brominated congeners but also contains tetra- and hexa-brominated congeners. In this report, 'commercial' will be used when referring to the commercial formulations, for example, commercial penta-BDE. If 'commercial' is not used then only the congeners with the corresponding level of bromination are being considered, for example penta-BDE refers only to PBDEs with 5 bromine atoms.

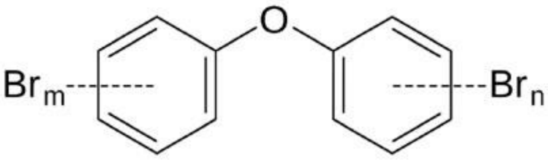


Figure 7: Chemical structure of polybrominated diphenyl ethers

Due to the persistence, toxicity and ability to bioaccumulate and biomagnify, commercial penta-BDE and commercial octa-BDE have been added to the Stockholm Convention's list of persistent organic pollutants, restricting their usage. According to NICNAS (National Industrial Chemicals Notification and Assessment Scheme) neither commercial penta-BDE or commercial octa-BDE are manufactured in Australia and available information indicates that neither of these commercial mixtures have been imported since 2005 but they are most likely imported into Australia in finished products. The production of these commercial mixtures was also halted in Europe and the USA as of 2004 and the use of commercial deca-BDE in electrical equipment has been restricted in Europe since 2008 (Kwan et al., 2013).

The current RRO has no testing and analysis requirements for PBDEs. Although there are these restrictions in place, PBDEs are still commonly found in a range of products. Due to the likely presence of PBDE containing materials in feedstock at AWT facilities, this group of compounds was incorporated into the study. This analysis was only incorporated into the later stages of the study due to the high cost of analysis and the availability of analytical methods. Analysis of the most commonly found PBDE congeners in the tri- to deca-BDE range was conducted using high resolution GS-MS following solvent extraction of the samples.

PBDE compounds were detected in all of the solid samples tested. Interestingly, the concentrations of PBDEs varied considerably between the two facilities. At Facility B, the concentrations of total PBDEs ranged from 0.096 to 0.97 mg/kg (average 0.34 mg/kg), whereas at the Facility A, the concentrations ranged from 3.8 to 720 mg/kg (average 125 mg/kg). The presence of PBDEs in the final product could be associated with plastics and the differences between the two facilities may be due to differences in the feedstock, differences in the removal processes prior to treatment and/or differences in the overall treatment processes.

Figure 8 shows a summary of the different brominated groups within the total PBDE concentration for six solid samples from each of the two facilities. For all of the samples, with the exception of the two samples that had the highest total PBDE concentrations (A2 and A6), over 50% of the PBDE profile was deca-BDE. For samples A2 and A6, which had the highest total PBDE concentrations, there were considerably higher proportions of hepta- and octa-BDE compounds in the overall chemical profile.

Only four batch extraction samples from each facility during SE5 were analysed for concentrations of PBDEs. The differences between the two facilities were considerably less variable compared to that observed for the solid material. Overall the total PBDE concentrations in the batch extractions ranged from 1.1 to 40 ng/kg (Figure 9). The PBDE profile of the batch extractions were considerably different to that observed in the solid material. Congeners in the groups tri-, nona- and deca-BDE were all below the LOQ in the batch extractions. This was considerably different to the solid material, which in most cases was dominated by deca-BDE. In the batch extractions, the PBDE profiles were dominated by congeners in the groups tetra-, penta- and hepta-BDE (Figure 9). Note that the concentration units for the batch extractions were ng/kg. For the remainder of this report it is assumed that the ratio of density between the mass and volume is 1:1. It is acknowledged however that this is likely to result in an under-estimation of the concentration due to an increased density of the solutions due to the high salt content and small particles (< 0.8 µm).

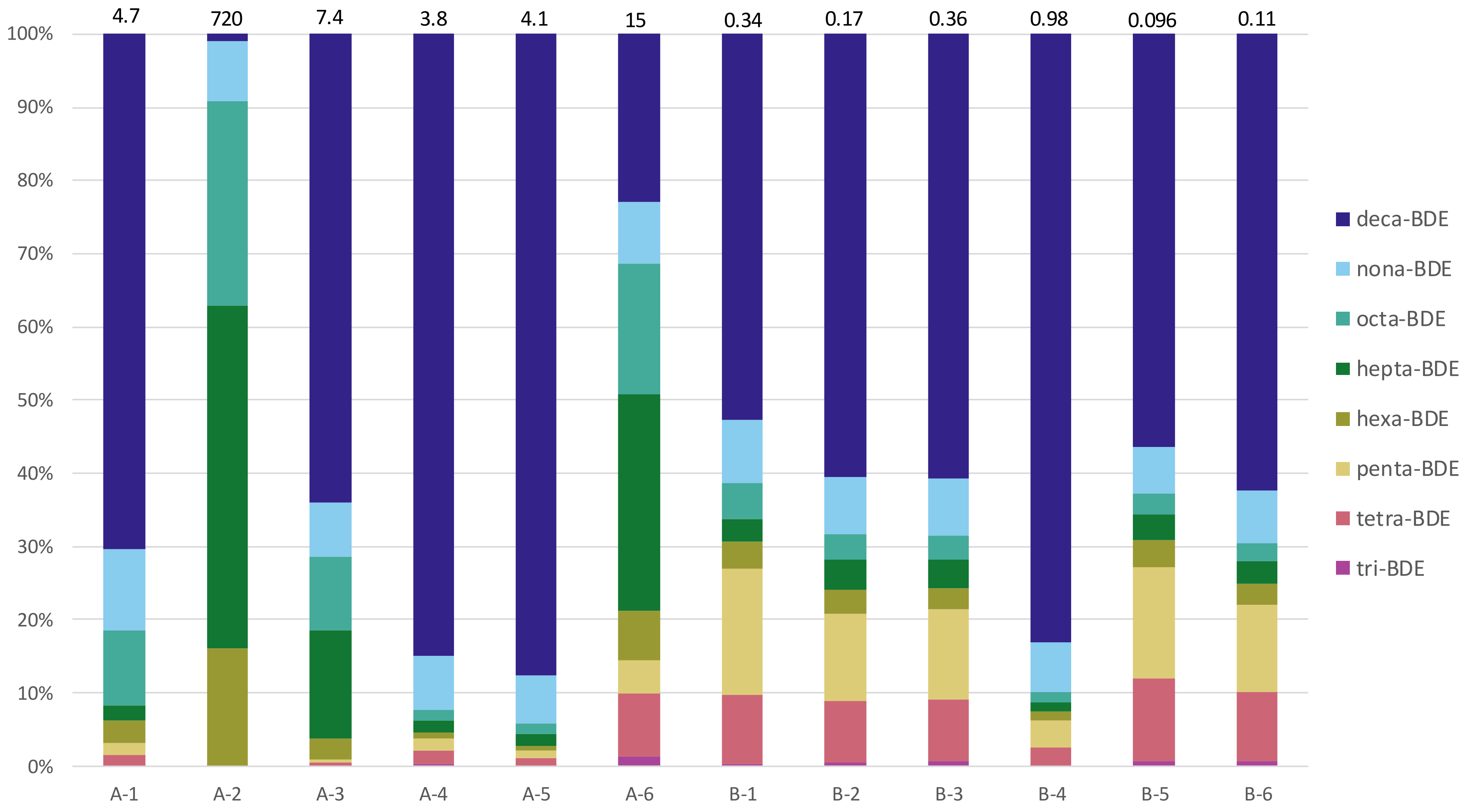


Figure 8: Summary of PBDE results in the MWOO solid samples from Facility A (A1-A6) and Facility B (B1-B6). The values above each bar indicate the total PBDE concentration of the sample in mg/kg.

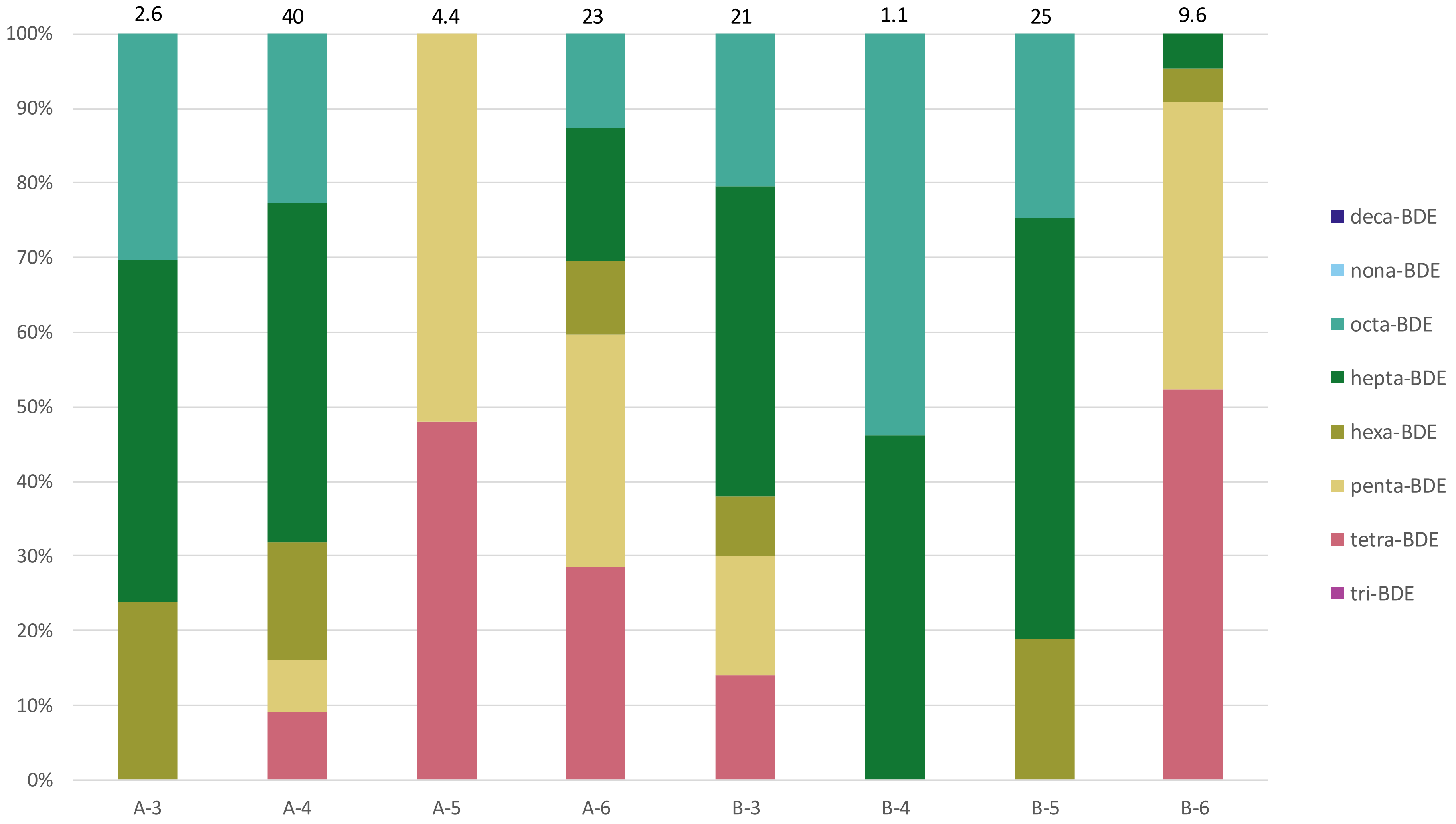


Figure 9: Summary of PBDE results in the batch extractions from Facility A (A3-A6) and Facility B (B3-B6). The figures above each bar indicate the total PBDE concentration of each sample in ng/kg (concentrations that were below the LOQ were excluded in the calculations).

3.15 Perfluorinated compounds

Perfluorinated compounds (PFCs) are organofluorine compounds that are used in a range of products as they have the benefit of making products resistant to stains, grease and water. For example, they are used in non-stick cookware, carpets, clothes, some food packaging and fire-fighting materials. In addition, they have a range of uses in industrial applications, including the automotive, building/construction and electronics industries. Two of the commonly found PFCs are perflorooctance sulfonate (PFOS) and perfluorooctanoic acid (PFOA), although there are many other compounds in commercial production. The primary concern relating to the presence of PFOS and PFOA in the environment is their extreme persistence, their ability to be readily absorbed into the body through ingestion, and their very slow elimination from the body in humans. There are no data to assess the acute toxicity of PFOS and PFOA, however, a range of toxic effects have been seen in animals following chronic exposure, including, effects on the liver, gastrointestinal tract and thyroid levels. The manufacturing of both compounds is now either banned or restricted in the USA and the compounds have never been manufactured in Australia. There are currently no requirements in the RRO for testing and analysis of PFCs.

PFOS and PFOA were included in this study at the later stages due to their extensive use in many products. One sample from each facility was subject to analysis, in order to provide some preliminary concentration data. Analysis was conducted by high performance liquid chromatography tandem mass spectrometry (HPLC-MSMS). The concentrations of both compounds in the MWOO solids and leachates were found in all cases to be below the LOQ. It should be noted however that the LOQs for PFOS and PFOA in the leachates were 1 µg/L and in the solids ranged from 1-3 µg/kg. These LOQs, particularly for the leachates, are above threshold values that are currently being developed in Australian and Internationally. As analytical methods have improved considerably for these compounds since this analysis was conducted, it is recommended that additional sampling and testing for these compounds in MWOO be conducted.

3.16 Asbestos

Asbestos is commonly associated with building and demolition waste. Fibres from asbestos can be released into the air when asbestos products are incorrectly handled, stored or transported. These fibres are hazardous when inhaled. The MWOO RRO has a requirement that the processor must ensure that the organic outputs do not contain any asbestos. Based on this requirement, asbestos analysis was conducted on solid material during this study. Asbestos was not detected in any of the samples, therefore, it will not be discussed further in this report.

4 Ecotoxicity testing of batch extractions and column leachates

4.1 Standard toxicity testing

As there was a complex mixture of chemicals present in the MWOO leachates, aquatic toxicity testing was undertaken during SE4 and SE5. This gives an indication of the toxicity of the leachate, which is a complex mixture of all these chemicals. As the combinations of chemicals maybe influence their toxicity (e.g. synergistic or antagonistic effects) and there may be different degrees of bioavailability in the leachates, the toxicity testing conducted considers the complete mixture within the leachates rather than considering individual chemicals.

The aquatic toxicity testing was conducted on the batch extractions and column leachates (F1-F4) (SE4 and SE5) and consisted of three standard toxicity tests:

1. Acute *Ceriodaphnia dubia* (cladoceran) 48 hr immobilisation test (USEPA, 2002)
2. Acute Microtox® *Vibrio fischeri* (luminescent bacteria) 30 min luminescence inhibition test (Microbics Corporation, 1995)
3. Chronic *Pseudokirchneriella subcapitata* (microalgae) 72 hr growth inhibition (cell yield) test (Environment Canada, 1992, USEPA, 2002).

These specific test organisms were selected as they represent multiple trophic levels in aquatic ecosystems. The detailed toxicity testing procedures are outlined in the 2014 Progress Report. In brief, prior to the commencement of the toxicity testing, the batch extractions and column leachate fractions were prepared into a range of test treatments with increasing percentages of leachate with deionised water. The test organisms were then exposed to the range of leachate concentrations for a specific time period (outlined above). At the completion of the toxicity tests the effect on the organisms was quantified by measuring a response. For *C. dubia*, the response was immobilisation (no movement or activity), for *V. fischeri* the response was luminescence (indicating bacterial cell yield) and for *P. subcapitata* algae growth was measured (cell yield). Concentration response curves were then produced by plotting the measured response against the corresponding leachate concentration (%). Following this, parametric and nonparametric statistical techniques were used to determine the concentrations of leachate that produced a specific percentage reduction of a given response. For example, the leachate concentration that produced a 50% reduction in cell growth relative to the control in a chronic microalgae test (i.e. EC50).

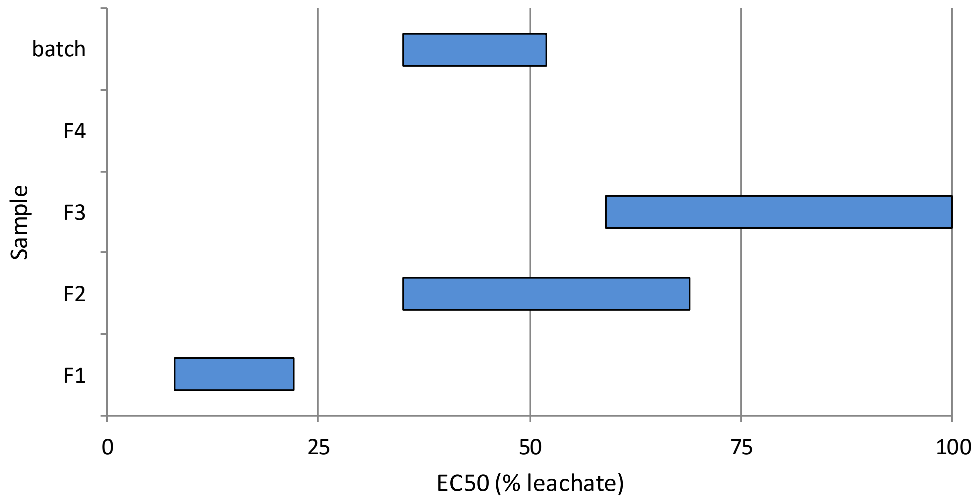
All of the toxicity tests were conducted in NATA accredited laboratories following the QA/QC requirements of ISO/IEC 17025:2005. Test results were only used where quality control criteria were satisfied. Refer to 2014 Progress Report for more information about the quality control criteria for each test. In addition, a reference toxicant test was included in each set of tests. The results from the reference toxicity test had to be within an acceptable range to ensure appropriate health of the test organisms and correct implementation of test procedures.

A summary of the range of EC50 values for each test species is shown in Figure 10. The F1 fraction was consistently the most toxic to all three test organisms, with 50% effects observed with <1% to 22% leachate. The EC50 of <1% was for one of the F1 fraction samples to the microalga *P. subcapitata*. It is unknown why this sample showed such high toxicity, however, this may be due to herbicides present in the leachate. For all species, there was then a decreasing trend in the toxicity (i.e. the samples became less toxic) with subsequent samples from F1 to F4, as evidenced by the increasing EC50 values. This result is consistent with the chemical leaching profiles discussed in Section 3. In the case of *C. dubia*, none of the F4 samples produced a 50% effect (therefore no data are shown in the corresponding figure). For each species, the toxicity of the batch extractions were found to be roughly consistent with the F2 fraction (Figure 10).

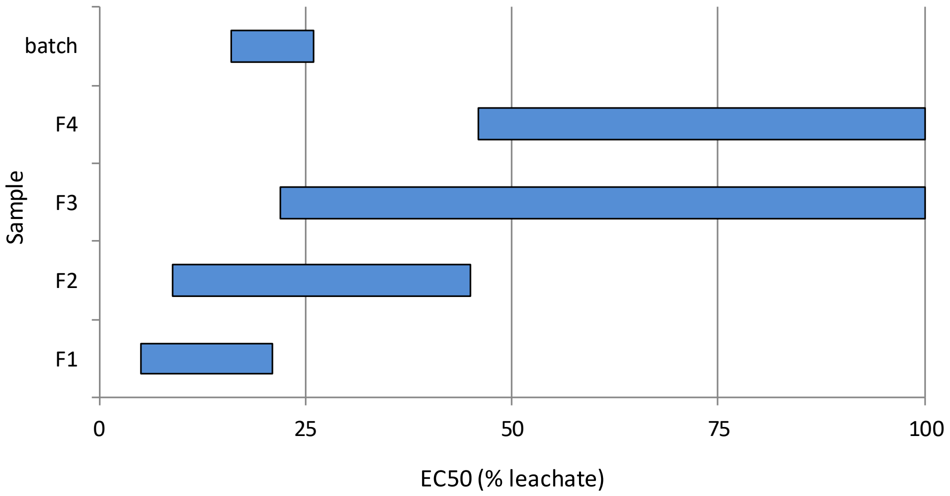
Each of the test species also showed varying sensitivities to the leachates (Figure 10). *C. dubia* was the least sensitive to the MWOO leachates as the range of EC50 values for this species was the highest (i.e. more leachate was require to exert a negative effect). In contrast, *P. subcapitata* showed the greatest sensitivity to the leachates as in most cases the EC50 values for this test species were the lowest. This result may be due in part directly to the species sensitivity, however, it should be noted that the *P. subcapitata* toxicity test is a chronic test, which normally results in more pronounced effects compared to acute tests.

In addition to the toxicity that was observed (Figure 10), in some cases a stimulatory response was observed in the test organism prior to the inhibition or toxic effect. This was particularly the case for the *P. subcapitata* growth test. This pattern of response is likely to be a direct response to the nutrients present in the samples.

(a) *C. dubia*



(b) *V. fischeri*



(c) *P. subcapitata*

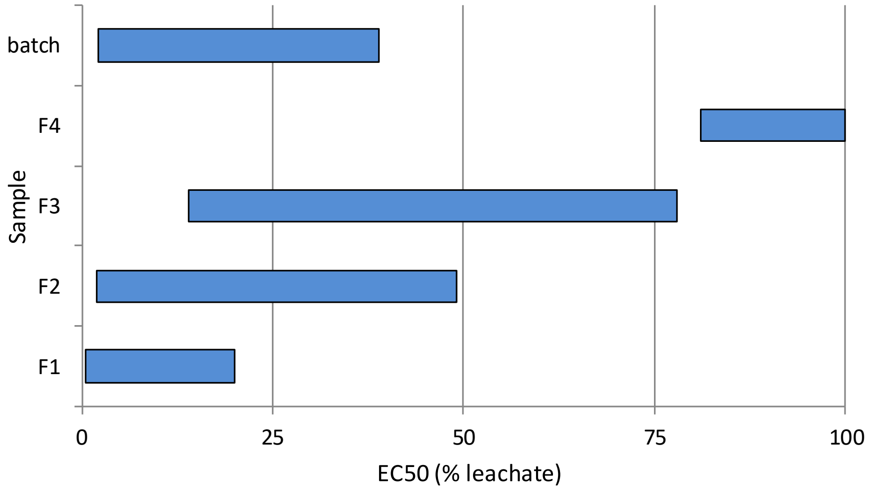


Figure 10: Summary of EC50 values for the F1, F2, F3, F4 and batch leachates to (a) *C. dubia*, (b) *V. fischeri* and (c) *P. subcapitata*. Note that for *C. dubia* a 50% effect was not observed for the any of the F4 samples.

4.2 Toxicity Identification Evaluation (TIE)

The F1 column leachate samples from SE4 and SE5 were used to conduct toxicity identification evaluation (TIE) (USEPA, 1991, USEPA, 1993a, USEPA, 1993b). The aim of this procedure is to highlight specific toxicants or groups of toxicants that are contributing to the toxicity of leachates. The TIE procedure combines toxicity testing with chemical and/or physical manipulations to identify specific toxicants in complex samples.

The 48 hr *C. dubia* immobilisation test was used for the TIE in this project as this species showed the most consistent toxicity results of all the standard tests. The TIE procedure involves three phases: Phase I characterisation of the leachates to determine the groups of chemicals responsible for toxicity; Phase II identification of suspect toxicants(s); and, Phase III confirmation of the suspected toxicant(s). Each phase is outlined in detail in the 2014 Progress Report.

The primary toxicants in the leachates identified through the TIE investigation were the pH-sensitive chemicals ammonia and sulfide, as well as major ions (measured as EC). The manipulations conducted on the leachates for the TIE did not completely remove the toxicity, indicating that other toxicants may also be contributing to the toxicity of the leachates. In addition, the TIE procedure in this study was conducted using one test species (*C. dubia*). Different species may have different sensitivities to toxicants or some toxicants may only exhibit effects following longer chronic exposures. These aspects should be considered when interpreting the TIE results from this study.

Part II: Preliminary screening assessment

Section Summary

Prior to conducting a detailed hazard assessment of the chemicals found in the MWOO solids and leachates, a preliminary screening assessment was conducted. For the solid material, this was done by comparing the 95th percentile of concentration data for each chemical with criteria concentrations that are protective of ecological and human receptors. For the leachates, this was done by comparing the maximum concentrations from the F1 fraction of the column leachates to corresponding criteria concentrations protective of ecological and human receptors, as well as agricultural receptors via exposure through livestock drinking water and irrigation water. The maximum concentrations had to be used for the leachates due to the small number of leachate samples collected. The criteria concentrations used were primarily guideline values from Australian sources. If no Australian guidelines were available, guidelines from other countries were used. If no guidelines were available, toxicity data were used to derive the criteria concentrations using an assessment factor approach (ecological receptors only).

In cases where the 95th percentile (solids) or maximum (leachates) concentration of a chemical exceeded any of the criteria concentrations (chemicals listed in Table 4), the chemical was assessed further in the following Parts of this report. In cases where the 95th percentile or maximum concentration was less than the corresponding criteria concentration, the chemical was excluded from further assessment and was considered to be of negligible concern. This approach is designed to be highly conservative as it uses 95th percentile or maximum concentrations, however, it is consistent with a screening assessment, which is used to identify chemicals that require further investigation.

There were also a number of chemicals for which screening could not be completed, as no criteria concentrations were available. These chemicals have been excluded from further assessment in this report, however, they should not be considered as negligible concern. Rather the potential concern around these chemicals is ‘unknown.’ These chemicals should be assessed when more information becomes available.

Finally an additional preliminary screen for secondary poisoning was conducted to identify organic compounds that were detected in the MWOO that might have to potential to biomagnify. This screen identified 8 compounds in the MWOO that have the potential to biomagnify, including phenanthrene, pyrene, DEHA, DEHP, dibutyl phthalate, 4OP, 4NP and PBDEs. These compounds should be considered further for their secondary poisoning risk in future risk assessment work.

Table 4: Chemicals highlighted for further assessment from the preliminary screening assessment for each receptor exposed to the solids and leachates

Solids		Leachates			
Ecological	**Human Health**	**Ecological**	**Human Health**	**Livestock drinking**	**Irrigation**
Aluminium	Lead	Aluminium	Antimony	Aluminium	Aluminium
Boron	Molybdenum	Antimony	Arsenic	Cadmium	Arsenic
Cadmium	Tin	Arsenic	Cadmium	Copper	Boron
Copper	Bis-2-ethylhexyl phthalate	Barium	Chromium	Lead	Cadmium
Lead	PBDEs	Boron	Copper	Manganese	Chromium
Lithium		Cadmium	Lead	Nickel	Cobalt
Manganese		Chromium	Manganese	Calcium	Copper
Mercury		Cobalt	Mercury	Chloride	Iron
Nickel		Copper	Molybdenum	Nitrite	Manganese
Silver		Iron	Nickel	Electrical conductivity	Molybdenum
Titanium		Lead	Sulfate		Nickel
Vanadium		Manganese	2,4-D		Zinc
Zinc		Mercury	MCPA		Sodium
Phenol		Molybdenum	Nitrate		Chloride
Benzyl butyl phthalate		Nickel	Nitrite		Dicamba
Bis-2-ethylhexyl adipate		Strontium			Phosphorus
Bis-2-ethylhexyl phthalate		Tin			Electrical conductivity
Dibutyl phthalate		Titanium			Sodium adsorption ratio
Bisphenol A		Vanadium			
Dibutyl tin		Zinc			
Penta-BDE		Chloride			
Electrical conductivity		Sulfate			
		Sulfide			
		3+4 methylphenol			
		Phenol			
		Hepta-BDE			
		Dicamba			
		MCPA			
		Total Ammonia			
		Nitrate			
		Nitrate (stressor)			
		Phosphorus (stressor)			

Solids		Leachates			
Ecological	**Human Health**	**Ecological**	**Human Health**	**Livestock drinking**	**Irrigation**
		FRP* (stressor)			
		Ammonium (stressor)			
		Electrical conductivity (stressor)			

* FRP – free reactive phosphorus

5 Procedure for preliminary screening assessment

Prior to conducting a detailed hazard assessment to identify specific high priority chemicals in the MWOO, a preliminary screen was conducted. This process considered a range of exposures to human, ecological and agricultural and was done to remove the chemicals from the assessment that were unlikely to be found in MWOO solids or leachates at concentrations that would be of concern. The chemicals (and other parameters) that were identified through this process were then subject to a more detailed hazard assessment and data quality assessment in Part III of this report. It is important to note that this assessment only considers chemical contaminants and does not consider biological contaminants (pathogens). Some preliminary analysis of pathogens in the MWOO was undertaken as part of this study (refer to 2013 and 2014 Progress reports). However, these data were considered indicative only, and it is recommended that a more detailed sampling and assessment of biological risks be conducted in a separate study, to address this issue more thoroughly than was possible in this project.

The preliminary screening procedure involved comparing the 95th percentile concentrations of chemicals in the solid material and the maximum concentrations of chemicals in the leachates against relevant criteria concentrations. The 95th percentiles were used for the solid material as this removed any concentrations that were outliers. This approach could not be used for the PBDE compounds in the solid material due to the small number of samples (n = 12) and the large variability in the data. Therefore for PBDE compounds in the solids, the maximum concentrations were used for the screening assessment. For the leachates, the maximum concentrations from the F1 sample of the column leachates were used for the screening assessment, due to the small number of samples. Overall, this is a very conservative approach, however, it is consistent with a screening assessment, which can be used to identify chemicals that require further investigation. The receptors and type of exposures considered included:

- Terrestrial exposure to solid material
    - Ecological effects – potential exposure to terrestrial organisms at a site following land application
    - Human health effects – potential exposure to humans at a site following land application
- Aquatic exposure to leachates
    - Ecological effects – potential exposure to aquatic organisms following leachate or surface run-off from a site entering surface waters
    - Human health effects – potential exposure to humans via ingestion following leachates entering a groundwater bore used for domestic purposes

- Agricultural (irrigation and livestock drinking) – potential exposure following leachates or surface run-off entering groundwater bores or surface waters used for agricultural purposes.

These different potential exposures to MWOO solids and leachates are also depicted as a generic conceptual model in Figure 11. This model shows that there is the potential for direct exposure to humans and terrestrial ecological receptors at the site of application. There is also the potential for leachate and surface-run-off to move off-site and into groundwater and surface water where aquatic, human and agricultural receptors (stock and irrigation) may be exposed.

Figure 11: Conceptual model for potential exposures to MWOO solid material and leachates

The preferred source for criteria concentrations were guideline values from Australian sources. The preference to use Australian guidelines was because these are generally considered to be relevant to Australian ecosystems and have been derived using nationally accepted protocols. If no Australian guidelines were available, guidelines from other countries were used, which in some cases use different protocols to derive their values. If no guidelines were available, toxicity data were used to derive the criteria concentrations using an assessment factor approach (ecological receptors only). Each of the difference sources of guidelines used in this assessment have different levels of reliability, however the use of a range of sources allowed more chemicals to be screened and assessed. The reliability of the criteria concentrations is discussed in more detail as part of the hazard assessment and data quality assessment presented in Part III.

5.1 Assessment of solid material

5.1.1 Ecological effects

The primary source of criteria concentrations for exposure of terrestrial ecological receptors was the National Environment Protection (Assessment of Site Contamination) Measure (NEPM) (NEPC, 2013b). The protection of ecological receptors is incorporated into the NEPM as ecological investigation levels (EILs). The derivation of an EIL for a given chemical requires two pieces of information: the added contaminant level (ACL) and the background concentration of the chemical. A site specific EIL is then derived by summing these two pieces of information. For this assessment, only the ACLs were used as the criteria concentrations as the land application of MWOO is the process by which contaminants may be added to a system.

The ACLs have been developed for assessing the risk to terrestrial ecosystems from selected metals. For most chemicals, site specific ACLs can be derived using the information provided in the NEPM and information known about the site being considered. Therefore, they are site specific in terms of the land use scenario and the soil physico-chemical properties. There are also some cases where generic ACLs for chemicals are provided that do not consider different soil properties. The ACLs are concentrations above which further assessment and evaluation is required. Exceedances do not necessarily indicate that ecological harm will occur.

The ACL for a chemical is the amount that can be added to a soil ensuring that a specified protection level is maintained. They have been developed to be protective of soil microorganisms, soil invertebrates, flora and fauna. The ACLs are generally dependant on soil type and have been developed using species sensitivity distributions (SSDs) (for more detail refer to Schedule B5a-c of the NEPM). Considering that MWOO may be added to a range of soil types, for this study conservative values were used for the different factors used to determine the ACL for a given chemical. These factors and the values used for this study are summarised below.

- **Toxicity data used for the SSD** – The results from toxicity testing can be presented in different ways, including no/low observed effect concentrations (NOEC and LOEC, respectively) that are based on hypothesis testing, or effect concentrations based on regression models that indicate a concentration corresponding to a specified % effect (e.g. EC10 or EC50, 10% or 50% effect concentrations, respectively). In the NEPM, three sets of toxicity data have been used to derive ACLs. These include, NOEC/EC10s (corresponding to slight toxic effects), LOEC/EC30s (corresponding to moderate toxic effects) and EC50s (corresponding to significant toxic effects).

In this study – the ACLs that correspond to the NOEC/EC10 toxicity data were used for this assessment. This was done to be conservative as these values correspond to 'slight toxic effects' (NEPC, 2013b).

- **Level of protection and land use scenario** – the level of protection indicates the percentage of species that will be protected by the ACL based on the SSD for a given chemical. Three different levels of protection have been used to derive ACLs that correspond to different land use scenarios. These are 99% protection for areas of ecological significance (e.g. National Parks), 80% protection for urban residential/public open spaces and 60% protection for commercial/industrial (note that if chemicals are known to biomagnify, the protection levels used are 99, 85 and 65%, respectively) (NEPC, 2013b; NEPC, 2013c).

  In this study – the ACLs that correspond to the urban residential/public open space land use scenario were used for this assessment as these were considered to be the most relevant for this scenario.

- **Fresh or aged contamination** – this has an influence on how biologically available (bioavailable) a chemical will be in the soil. Over time, chemicals generally become less bioavailable and therefore less toxic in soils due to binding with soil particles, chemical and biological degradation and a range of other processes. In the NEPM, ACLs have been derived for both fresh contamination (< 2 yrs old) and aged contamination (> 2 yrs old).

  In this study – the ACLs that were derived for fresh contamination have been used for this assessment. This is based on the assumption that MWOO is produced and applied to land in a period < 2 yrs.

- **Effect of soil type** – different soil types will result in varying bioavailability of chemicals due to different sorption capacities. A soil with a high sorption capacity is able to bind a greater amount of a chemical than a soil with a low sorption capacity, lowering the bioavailability of that chemical. This means a soil with a high sorption capacity may be able to hold a greater mass of a chemical before toxicity is observed. For selected metals, the NEPM provides soil-specific ACLs that have been determined based on toxicity relationships with soil properties. Different properties or combinations of properties are used for different metals, however, the main properties to be considered are pH, cation exchange capacity (CEC) and clay content. Generally, as these properties decrease, the sorption capacity of the soil for cationic metals decreases. For example, a soil that has low pH, CEC and clay content will have a low capacity to sorb/bind metals, resulting in a lower ACL.

  In this study – as a conservative approach, soil properties that would result in a weakly binding soil were used for the assessment. These were $pH_{(CaCl2)}$ = 4.5, CEC = 5 $cmol_c$/kg and clay content = 1%.

In cases where no ACLs were available in the NEPM, guideline values from other countries were used as the criteria concentrations for the preliminary screening assessment. These included the European Chemicals Agency (ECHA) predicted no effect concentrations (PNECs), USEPA Ecological soil screening levels (Eco-SSLs), Canadian Council of Ministers of the Environment (CCME) soil quality guidelines for environmental health (SQG_E) and screening quick reference tables (SQuiRTs). The preferred source was the ECHA PNECs as these were considered to be the most up to date. Following that, the USEPA and CCME SQG_E were the next preference and if a criteria concentration was found for a chemical in both of these sources then the lowest value was used. The final preference was the SQuiRTs. Information about each of these sources is summarised below (more detail is provided in Section 10.1).

- **European Chemicals Agency (ECHA) predicted no effect concentrations (PNECs)** are concentrations below which negative environmental effects are not expected to occur. Depending on the total number and type of data available, PNECs are derived using probabilistic approaches (e.g. SSDs), deterministic approaches or equilibrium partitioning techniques.
- **USEPA Eco-SSLs (soil screening levels)** are contaminant concentrations that are protective of ecological receptors that can be applied at the screening stage of ecological risk assessments. They have been derived separately for plants, soil invertebrates, birds and mammals. In this study, when Eco-SSLs were used, the lowest concentration (corresponding to the most sensitive ecological receptor) was used.
- **Canadian Council of Ministers of the Environment (CCME) soil quality guidelines for environmental health (SQG_E)** are guideline concentrations based on soil contact using plants and invertebrates. Concentrations are provided for different land use scenarios including, agricultural, residential/parkland, commercial and industrial. In this study, when the CCME SQG_Es were used, the concentrations for the agricultural land use scenario were used.
- **Screening Quick Reference Tables (SQuiRTs)** (http://archive.orr.noaa.gov/book_shelf/122_NEW-SQuiRTs.pdf) provide screening concentrations for organic and inorganic contaminants in various environmental media.

In cases where criteria concentrations for soil ecological systems could not be obtained from any of the above sources, a criteria concentration was determined based on available ecotoxicology data and application of an assessment factor. The approach used in these cases was based on the approach outlined in the NEPM Schedule B5b (NEPC, 2013c). In this approach, the lowest toxicity value for a chemical is divided by an assessment factor to derive a guideline value or criteria concentration. The magnitude of the assessment factor depends on the available toxicity data and these are summarised in Table 5. For chemicals where this approach was used, a summary of all toxicity data considered and the assessment factor used can be found in Appendix B.

Table 5: Assessment factors used to derive criteria concentrations using the assessment factor approach (adapted from NEPC, 2013c)

Number of species (or soil processes)	Number of taxonomic groups (or nutrient groups)	Assessment factor
< 3 species	Not applicable	500
≥ 3 species	1	100
≥ 3 species	2	50
< 5 species	3	10

5.1.2 Human health effects

The primary source for criteria concentrations to conduct the preliminary screening assessment for human health exposure to the MWOO solid material was also the NEPM. The NEPM presents health investigation levels (HILs) that can be used to conduct a tier 1 assessment for human health exposure to contaminants present at contaminated sites. HILs are available for a wide range of metals and organic compounds, applicable for assessing human health risk via exposure pathways of incidental ingestion and dermal contact. Exposure via inhalation is also covered in the NEPM for a range of volatile compounds, however, these were not considered relevant in this assessment. The NEPM provides HILs for various chemicals in soil under a range of land use scenarios, as follows:

- **HIL A** – residential with garden accessible soil (home grown produce < 10% fruit and vegetable intake (no poultry), also includes childcare centres, preschools and primary schools
- **HIL B** – residential with minimal opportunity for soil access, includes dwellings with fully and permanently paved yard space such as high-rise buildings and apartments
- **HIL C** – public open space such as parks, playgrounds, playing fields (e.g. ovals), secondary schools and footpaths
- **HIL D** – commercial/industrial, includes premises such as shops, offices, factories and industrial sites.

The HILs for each of these land use scenarios vary, as the assumptions used to derive the values vary based on different exposures. For more details on the assumptions used for the derivation of the HILs refer to Schedule B7 of the NEPM. The assumptions and the resulting HILs are designed for screening only, that is they use conservative assumptions to identify pollutants that require further investigation. Exceedance of any HIL does not indicate that harm will occur but rather indicates that further investigation and evaluation is warranted. If the concentration of a chemical is below the relevant HIL then it is considered that the risk to human health from exposure will be negligible. In this project, the HIL A concentrations were used to compare with the concentrations in the MWOO. It is acknowledged that this land use is not consistent with the intended land use of MWOO, however, these values provide a conservative assessment of the chemical concentration data.

For chemicals that did not have corresponding HILs in the NEPM, guideline values from other countries were used as the criteria concentrations. The sources used for this process were (presented in order of preference):

- **CCME Interim Remediation Criteria (IRC)** are concentrations of contaminants in soil that are considered to be generally protective of human and environmental health for specific land uses, based on experience and professional judgement. The IRCs are not effects-based and are recommended for use until effects-based soil quality guidelines (SQGs) become available. In instances where more recent effects-based SQGs have been developed by CCME, but these values are higher than the IRC, the more conservative IRC concentrations have been retained.
- **Dutch Intervention Values** are concentrations that indicate when the functional properties of the soil for human, plant and animal life are seriously impaired or threatened. They are representative of the levels of contamination above which there is a serious case of soil contamination.

5.2 Assessment of leachates

As outlined in Section 2.2, different methods were used to generate leachates during the study, including batch extractions, column leachate fractions and column leachate snapshots. To undertake the preliminary assessment of chemicals in the leachates the maximum concentrations in the first column fraction (F1) were used. This is considered to be a conservative approach as the F1 fraction always produced to highest concentrations of the chemicals. The only exception to this was some of the initial column leachate snapshots that had higher concentrations, however, as discussed in Section 2.2, these were conducted as part of the preliminary experimentation and were therefore not used for the assessment phase of the study.

5.2.1 Ecological effects (freshwater)

The primary source for criteria concentrations for the assessment of chemicals to aquatic ecological receptors was the Australian and New Zealand Water Quality Guidelines (WQGs) (ANZECC and ARMCANZ, 2000). These WGQs provide a range of trigger values (TVs) for freshwater and marine systems, however, for this assessment only the freshwater TVs were considered based on the following assumptions:

- Freshwater TVs are generally similar to or lower than the marine TVs, therefore, using only the freshwater values will generally be protective of marine systems
- Land receiving MWOO applications in NSW are more likely to be adjacent to freshwater systems than marine systems
- Dilution factors in marine systems are normally greater than in freshwater systems.

The freshwater TVs that are provided in the Australian WQGs are reported to be either low, moderate or high reliability based on the method used to derive them. The high reliability TVs were derived from multiple-species data or chronic data, using a risk-based statistical distribution method (i.e. SSD). The moderate reliability TVs also used a risk-based statistical distribution method but were based on acute toxicity data that were converted to chronic data using acute-to-chronic ratios. The low reliability TVs were derived when insufficient toxicity data were available to use the statistical distribution method. In these cases, assessment factors were used to account for the greater uncertainty in the data. The high and moderate reliability TVs are presented at a range of protection levels, 99, 95, 90 and 85% species protection. In most cases, the 95% protection concentrations are recommended for use and 99% for chemicals that bioaccumulate. The 95% protection level generally applies to slightly to moderately impacted systems and this is consistent with waterways that may receive agricultural run-off. For the assessment in this study, the concentrations corresponding to this level of protection were used. If TVs are exceeded for any chemical, it does not necessarily indicate that negative effects will occur but rather indicates a *potential* environmental problem that requires further investigation.

In addition to the toxicity based TVs outlined above, ANZECC and ARMCANZ (2000) provides guideline values for a range of physical and chemical stressors. These stressors can cause serious degradation of aquatic ecosystems when ambient values are too high and/or too low. Stressors can directly result in adverse changes to ecosystems (e.g. nutrients causing algal blooms) or they can cause indirect effects, for example, pH can affect the bioavailability of metals. Some pollutants can act both as stressors and toxicants. For example, ammonia acts as a nutrient but also can be acutely toxic to aquatic organisms. In this project, the stressors that were considered include nutrients, salinity (measured as EC) and pH. The Australian WQGs provide generic stressor guidelines for different geographical regions in Australia, for use where site-specific values are not available. In this study, the most sensitive generic guideline value has been used from the South-East Australia region.

For some chemicals (or parameters) in the leachates, Australian WQGs were not available. In these cases, guidelines from other countries were used to complete the preliminary screening assessment, if available. Of these other sources, the ECHA PNECs were the preferred source as these were considered to be the most up to date. For the remaining sources, criteria concentrations for individual chemicals were not found in multiple sources, therefore, no preferences were identified. The USEPA freshwater screening benchmarks were also considered but no criteria concentrations were used from that source. The sources used are summarised below:

- **European Chemicals Agency (ECHA) predicted no effect concentrations (PNECs)** – concentrations below which negative environmental effects are not expected to occur. Depending on the total number and type of data available, PNECs are derived using, probabilistic approached (e.g. SSDs), deterministic approaches or equilibrium partitioning techniques.
- **Canadian Council of Ministers of the Environment** (**CCME) water quality guidelines** – similar to the approach used in Australia, CCME derives WQGs using an SSD approach to determine a concentration that should theoretically protect 95% of species. For chemicals that do not have sufficient toxicity data to complete an SSD, an assessment factor is applied to the lowest toxicity data to account for any uncertainty.
- **British Colombia Ministry of Environment** – provides locally relevant ambient WQGs for variables that are important in the surface waters of British Columbia. These values have been set considering the scientific literature, guidelines from other jurisdictions and local environmental conditions.
- **Canadian Federal Environmental Quality Guidelines (water)** – benchmarks for the quality of ambient environment. When the guideline values are met, there is a low likelihood of adverse effects. They use available aquatic toxicity data and apply an assessment factor if required.
- **Screening Quick Reference Tables (SQuiRTs)** (http://archive.orr.noaa.gov/book_shelf/122_NEW-SQuiRTs.pdf) – provide screening concentrations for organic and inorganic contaminants in various environmental media.

At the completion of this process, there were still a number of chemicals that had been detected in the MWOO leachates that did not have corresponding criteria concentrations to complete the preliminary screening assessment. In these cases, a similar approach was used to that outlined previously for soil ecological effects (Section 5.1.1), which used ecotoxicological data with an assessment factor. See Appendix B for a list of all toxicity data considered and the assessment factors used to derive the criteria concentrations in these cases.

5.2.2 Human health effects (drinking water)

The guidelines available in Australia to protect human health from contaminant risks in water include the Australian Drinking Water Guidelines (ADWGs) (NHMRC, 2011) and the Guidelines for Recreational Water Quality (ANZECC and ARMCANZ, 2000). The more recent Guidelines for Managing Risks in Recreational Water (NHMRC, 2008) suggest a screening approach for recreational waters by multiplying the drinking water guideline by 10 to determine a screening level concentration for recreational waters. This is based on the assumption that the contribution of water ingested from swimming would be no more than 10% of the total water consumed daily. Therefore, in this study only the ADWGs were used, as these concentrations will be protective of recreational waters. For this assessment, only drinking water guidelines to protect human health were considered and guidelines for aesthetic considerations were not included.

5.2.3 Agricultural (irrigation water and livestock drinking water)

Two agricultural exposure were considered for the preliminary screening assessment of the MWOO leachate data. These were the use of water for irrigation purposes and livestock drinking water. The ANZECC and ARMCANZ (2000) WQGs provide TVs that correspond to both of these scenarios. These TVs have been derived using information from previous guidelines, extensive literature reviews, recent research data and input from public comment (ANZECC and ARMCANZ, 2000). In developing the irrigation water guidelines, the water quality characteristics that affect agricultural production, catchment condition and downstream water quality were evaluated. The TVs for livestock drinking water were based on current literature, material provided by the public and field observations. ANZECC and ARMCANZ (2000) states that most of the TVs for livestock drinking water require further validation and should be considered as interim values.

Additional sources of guideline values for livestock drinking water and/or irrigation water included:

- The CCME Canadian WQGs for the Protection of Agricultural Water Uses
- '*Livestock Water Quality: A Field Guide for Cattle, Horses, Poultry and Swine*,' produced by the University of Saskatchewan with Agriculture and Agri-Food Canada (Olkowski, 2009).

6 Outcomes from the preliminary screening assessment

The criteria concentrations that were identified for each chemical (or parameter) from the sources outlined above are summarised in Table 6 and Table 7. For some chemicals, no criteria concentrations could be sourced. In these cases the screening could not be completed. In some cases, the degree of concern is mitigated due to one or more of the following reasons:

- Individual chemicals are covered through the assessment of another parameter, for example, major cations and anions are incorporated into the general measurement of EC
- Individual chemicals are covered by criteria concentrations that consider groups of chemicals, for example, total PAHs, organotins and PBDEs
- Chemicals had very low detection frequencies, for example, several of the pesticide compounds were only detected in 1 or 2 samples.

Even where the above mitigating factors apply, chemicals that could not be screened should not be considered to be of no concern. Instead, the concern around these chemicals in MWOO should be considered 'unknown' and they should be assessed when more information becomes available.

Table 6 and Table 7 indicate the chemicals for which the 95th percentile (solids) or maximum (leachates) concentrations exceeded the available criteria concentrations. The greatest number of chemicals (or groups of chemicals) identified for further assessment were for the ecological receptors (terrestrial and aquatic). All of the chemicals identified through the preliminary screening are discussed further in the following sections in a more detailed hazard assessment.

A large number of chemicals were identified as being of negligible concern based on comparison with the criteria concentrations (Table 6 and Table 7). These chemicals were not assessed further as part of this study as they are considered unlikely to be present in MWOO at concentrations that are of concern to human health or the environment.

Table 6: Summary of 95th percentile concentrations of chemicals in mixed waste organic outputs, criteria concentrations and requirement for further assessment

Chemical group	Chemical/parameter	95th percentile concentration (mg/kg)*	Ecological		Human health	
			Criteria conc (mg/kg)	Further assessment	Criteria conc (mg/kg)	Further assessment
Metals and metalloids	Aluminium	8455	50[e]	**YES**	na	-
	Antimony	12	37[d]	NO	20[h]	NO
	Arsenic	9.7	20[a]	NO	100[g]	NO
	Barium	200	330[b]	NO	500[h]	NO
	Beryllium	0.32	21[b]	NO	60[g]	NO
	Boron	28	5.7[d]	**YES**	4500[g]	NO
	Cadmium	3.9	0.9[d]	**YES**	20[g]	NO
	Chromium	63	75[a,v]	NO	100[g,r]	NO
	Cobalt	6.1	10.9[d]	NO	100[g]	NO
	Copper	1200	20[a]	**YES**	6000[g]	NO
	Iron	17000	na	-	na	-
	Lead	340	130[a]	**YES**	300[g]	**YES**
	Lithium	2.8	1.76[d]	**YES**	na	-
	Manganese	410	3.4[d]	**YES**	3800[g]	NO
	Mercury	0.62	0.022[d]	**YES**	40[g,s]	NO
	Molybdenum	6.5	20.4[d]	NO	5[h]	**YES**
	Nickel	43	10[a]	**YES**	400[g]	NO
	Silver	2.2	1.41[d]	**YES**	30[h]	NO
	Strontium	110	332[d]	NO	na	-
	Sulfur	4200	na	-	na	-
	Tin	36	50[e]	NO	5[h]	**YES**
	Titanium	120	60[d]	**YES**	na	-
	Vanadium	17	6.0[d]	**YES**	130[h]	NO
	Zinc	730	25[a]	**YES**	7400[g]	NO

Chemical group	Chemical/parameter	95th percentile concentration (mg/kg)*	Ecological		Human health	
			Criteria conc (mg/kg)	Further assessment	Criteria conc (mg/kg)	Further assessment
Major cations	Calcium	34000	na	-	na	-
	Magnesium	3500	na	-	na	-
	Potassium	12000	na	-	na	-
	Sodium	7800	na	-	na	-
PAHs	Acenaphthene	0.36	20[e]	NO	na	-
	Fluoranthene	0.37	na	-	na	-
	Fluorene	0.35	na	-	na	-
	Naphthalene	1.6	70[a]	NO	3[g]	NO
	Phenanthrene	0.50	na	-	5[h]	NO
	Pyrene	0.39	na	-	10[h]	NO
	Total PAHs	2.5	18[b]	NO	300[g]	NO
Phenols	3+4 Methylphenol	44	na	-	400[g,t]	NO
	Phenol	60	0.13[d]	**YES**	3000[g]	NO
Plasticisers	Benzyl butyl phthalate	1.9	1.57[d]	**YES**	30[h]	NO
	DEHA	51	0.865[d]	**YES**	na	-
	DEHP	180	13[d]	**YES**	30[h]	**YES**
	Dibutyl phthalate	12	0.05[d]	**YES**	30[h]	NO
	Diethyl phthalate	1.9	137[d]	NO	30[h]	NO
	Dimethyl phthalate	1.8	3.16[d]	NO	30[h]	NO
	Di-n-octyl phthalate	1.9	na	-	30[h]	NO
Pesticides	Atrazine	1.5	na	-	320[g]	NO
	Bifrenthrin	0.47	na	-	600[g]	NO
	Endosulfan I	0.70	na	-	270[g]	NO
	Fipronil	0.021	na	-	na	-
	Gamma-chlordane	0.35	na	-	50[g]	NO
	Metalaxyl	0.0045	1.66[f]	NO	na	-

Chemical group	Chemical/parameter	95th percentile concentration (mg/kg)*	Ecological		Human health	
			Criteria conc (mg/kg)	Further assessment	Criteria conc (mg/kg)	Further assessment
	Prometryn	0.089	na	-	na	-
	Thiabendazole	0.045	0.21[f]	NO	na	-
	Trans-permethrim	0.540	na	-	na	-
	2,4,5-T	0.18	na	-	600[g]	NO
	2,4-D	0.18	0.3[f]	NO	900[g]	NO
	Dicamba	0.17	na	-	na	-
	MCPA	1.4	2.67[f]	NO	600[g]	NO
	MCPP	0.16	2.0[f]	NO	na	-
Emerging contaminants	4OP	0.47	2.3[d]	NO	na	-
	4NP	5.4	2.3[d]	NO	5.7[c]	NO
	BPA	66	3.7[d]	**YES**	na	-
Organotins	MBT	0.032	na	-	na	-
	DBT	0.027	0.00181[d]	**YES**	na	-
	TBT	0.0033	0.13[f]	NO	na	-
	Total organotins	0.058	na	-	2.5[i]	NO
Flame retardants	Polybrominated diphenyl ethers	715[w]	na	-	1[g]	**YES**[u]
	penta-BDE (commercial)	116[q,w]	0.38[d]	**YES**	na	**-**
	deca-BDE	7.5[w]	98[d]	NO	na	-
Other parameters	EC	14 (dS/m)	2[c]	**YES**	na	-

na indicates that no criteria concentration was available; dash ('-') indicates that the preliminary assessment could not be completed due to a criteria concentration not being available

* if the concentration of a chemical was below the LOQ, half the LOQ was used to calculate the 95th percentile.

Soil ecological criteria concentration source: [a] NEPM ACL; [b] USEPA Eco-SSLs; [c] CCME SQG$_E$; [d] PNEC from ECHA; [e] SQuiRT screening levels; [f] assessment factor approach (see Appendix B)

Soil human health criteria concentrations source: [g] NEPM HILs; [h] CCME IRC; [i] Dutch Intervention Values

Other information: [q] the 'commercial' penta-BDE concentration was estimated by summing tetra-, penta- and hexa-BDEs; [r] as Cr(VI); [s] as inorganic mercury; [t] HIL for cresol; [u] total PBDEs considered for comparison rather than just Br1-Br9 as outlined in the NEPM; [v] as Cr(III); w concentrations reported are maximum concentrations due to the small number of samples and the large variability in concentrations

Table 7: Summary of maximum concentrations of chemicals in mixed waste organic outputs leachates, criteria concentrations and requirement for further assessment

Chemical group	Chemical/parameter	Maximum concentration (mg/L)	Freshwater		Drinking water		Livestock drinking		Irrigation	
			Criteria conc (mg/L)	Further assessment	Criteria conc[j] (mg/L)	Further assessment	Criteria conc (mg/L)	Further assessment	Criteria conc (mg/L)	Further assessment
Metals	Aluminium	16	0.055[a]	**YES**	na	-	5[k]	**YES**	5[n]	**YES**
	Antimony	0.05	0.009[a]	**YES**	0.003	**YES**	na	-	na	-
	Arsenic	0.11	0.013[a,p]	**YES**	0.01	**YES**	0.5[k]	NO	0.1[n]	**YES**
	Barium	0.21	0.0039[f]	**YES**	2	NO	na	-	na	-
	Boron	1.9	0.37[a]	**YES**	4	NO	5[k]	NO	0.5[n]	**YES**
	Cadmium	0.04	0.0002[a]	**YES**	0.002	**YES**	0.01[k]	**YES**	0.01[n]	**YES**
	Chromium	0.47	0.001[a,s]	**YES**	0.05	**YES**	1[k]	NO	0.1[n]	**YES**
	Cobalt	0.21	0.0014[a]	**YES**	na	-	1[k]	NO	0.05[n]	**YES**
	Copper	7.2	0.0014[a]	**YES**	2	**YES**	0.4[k]	**YES**	0.2[n]	**YES**
	Iron	23	0.3[a]	**YES**	na	-	na	-	0.2[n]	**YES**
	Lead	0.4	0.0034[a]	**YES**	0.01	**YES**	0.1[k]	**YES**	2[n]	NO
	Lithium	0.08	16.9[e]	NO	na	-	na	-	2.5[n]	NO
	Manganese	7	1.9[a]	**YES**	0.5	**YES**	5[m]	**YES**	0.2[n]	**YES**
	Mercury	0.002	0.00006[a]	**YES**	0.001	**YES**	0.002[k]	NO	0.002[n]	NO
	Molybdenum	0.15	0.034[a]	**YES**	0.05	**YES**	0.15[k]	NO	0.01[n]	**YES**
	Nickel	2.6	0.011[a]	**YES**	0.02	**YES**	1[k]	**YES**	0.2[n]	**YES**
	Strontium	2.9	1.5[f]	**YES**	na	-	na	-	na	-
	Sulfur	300	na	-	na	-	333[m]	NO	na	-
	Tin	0.08	0.003[a]	**YES**	na	-	na	-	na	-
	Titanium	0.49	0.076[e]	**YES**	na	-	na	-	na	-
	Vanadium	0.06	0.006[a]	**YES**	na	-	0.1[l]	NO	0.1[n]	NO
	Zinc	14	0.008[a]	**YES**	na	-	20[k]	NO	2[n]	**YES**
Major Ions	Calcium	1200	na	-	na	-	1000[k]	**YES**	na	-

Chemical group	Chemical/parameter	Maximum concentration (mg/L)	Freshwater		Drinking water		Livestock drinking		Irrigation	
			Criteria conc (mg/L)	Further assessment	Criteria conc[j] (mg/L)	Further assessment	Criteria conc (mg/L)	Further assessment	Criteria conc (mg/L)	Further assessment
	Magnesium	190	na	-	na	-	400[m]	NO	na	-
	Potassium	1200	na	-	na	-	1400[m]	NO	na	-
	Sodium	870	na	-	na	-	1000[m]	NO	115[n,w]	**YES**
	Chloride	1100	120[b]	**YES**	na	-	1000[m]	**YES**	175[n,w]	**YES**
	Sulfate	790	50[c]	**YES**	500	**YES**	1000[k]	NO	na	-
	Sulfide	0.29	0.001[a]	**YES**	na	-	na	-	na	-
Phenols	3+4 methylphenol	0.4	0.0.1[e]	**YES**	na	-	na	-	na	-
	Phenol	2.3	0.32[a]	**YES**	na	-	na	-	na	-
Pesticides	2,4,5-T	0.001	0.036[a]	NO	0.1	NO	na	-	na	-
	2,4-D	0.037	0.28[a]	NO	0.03	**YES**	na	-	na	-
	Dicamba	0.015	0.01[b]	**YES**	0.1	NO	0.12[l]	NO	0.000006[o]	**YES**
	MCPA	0.063	0.0014[a]	**YES**	0.04	**YES**	na	-	na	-
	MCPP	0.01	0.6[g]	NO	0.01	NO	na	-	na	-
	Triclopyr	0.009	0.46[g]	NO	0.02	NO	na	-	na	-
Flame retardants*	Tetra-BDE	6.6 ng/L	24 ng/L[h]	NO	na	-	na	-	na	-
	Penta-BDE (commercial)	7.3 ng/L	530 ng/L[e]	NO	na	-	na	-	na	-
	Hexa-BDE	6.3 ng/L	120 ng/L[h]	NO	na	-	na	-	na	-
	Hepta-BDE	18 ng/L	17 ng/L[h]	**YES**	na	-	na	-	na	-
	Octa-BDE	9.1 ng/L	17 ng/L[h]	NO	na	-	na	-	na	-
Nutrients	Ammonia	520	0.9[a]	**YES**	na	-	na	-	na	-
	Total Phosphorus	20	na	-	na	-	na	-	0.8[m]	**YES**
	NOx-N (as nitrate)	22	0.7[a]	**YES**[r]	11.3	**YES**[r]	90[k]	NO[r]	na	-
	NOx-N (as nitrite)	22	na	-	0.9	**YES**[t]	9.1[k]	**YES**[t]	na	-
General parameters	EC	11 dS/m	na	-	na	-	2985[k,v]	**YES**	0.65[n,v]	**YES**
	Sodium adsorption ratio	14 (unitless)	na	-	na	-	na	**-**	4[n,x]	**YES**

Chemical group	Chemical/parameter	Maximum concentration (mg/L)	Freshwater		Drinking water		Livestock drinking		Irrigation	
			Criteria conc (mg/L)	Further assessment	Criteria conc[j] (mg/L)	Further assessment	Criteria conc (mg/L)	Further assessment	Criteria conc (mg/L)	Further assessment
Stressors[i]	NOx-N	22	0.01	**YES**						
	Total Phosphorus	20	0.01	**YES**						
	Free reactive P	8	0.008	**YES**						
	EC	11000 µS/cm	20	**YES**						
	Ammonium	520	0.01	**YES**[s]						

na indicates that no criteria concentration was available; dash ('-') indicates that the preliminary assessment could not be completed due to a criteria concentration not being available

Source used for criteria concentration for freshwater systems: [a] ANZECC & ARMCANZ, 2000 WQGs; [b] CCME WQGs; [c] British Colombia Ministry of Environment; [d] USEPA freshwater screening level; benchmarks; [e] ECHA PNECs; [f] SQuiRT screening levels; [g] assessment factor approach (see Appendix B); [h] Canadian Federal Environmental Quality Guidelines

[i] freshwater criteria for chemical stressors from ANZECC & ARMCANZ, 2000

[j] drinking water criteria concentrations sourced from ADWGs

Source used for livestock drinking water criteria concentration: [k] ANZECC & ARMCANZ, 2000; [l] CCME Guidelines for Livestock Water; [m] Guidelines from University of Saskatchewan (Olkowski, 2009)

Source used for irrigation water criteria concentration: [n] ANZECC & ARMCANZ, 2000; [o] CCME Guidelines for Irrigation Water

Other information: [p] as As(V); [q] as Cr(VI); [r] assuming all NOx-N is nitrate-N; [s] assuming total ammonia-N is NH_4^+-N; [t] assuming all NOx-N is nitrite; [u] calculated from total dissolved solids (ANZECC and ARMCANZ (Vol 4), 2000); [v] for sensitive crops (ANZECC and ARMCANZ (Vol 4), 2000); [w] concentrations to prevent foliar damage for sensitive crops (ANZECC and ARMCANZ (Vol 4), 2000); [x] lowest SAR for sensitive crops (ANZECC and ARMCANZ (Vol 4), 2000)

* leachate concentrations for flame retardants are from batch extractions

7 Preliminary screen for secondary poisoning potential

Secondary poisoning can occur if contaminants accumulate from the ambient environment into the tissues of organisms (bioaccumulation) that are then consumed by other organisms. The concentrations of some contaminants can increase through this process (biomagnification), resulting in toxicity being observed in organisms at the top end of the food chain (secondary poisoning).

Biomagnification is generally more relevant for organic compounds, however some metals are known to biomagnify. These include, mercury (especially methyl forms), cadmium and selenium (NEPC, 2013b). For organic compounds, the likelihood of biomagnification can be determined by considering the physico-chemical properties of the compounds, mainly the octanol-water partitioning coefficient (Kow). This parameter can be used to predict the lipophilicity of a compound and compounds with log Kow values greater than or equal to 4 are most likely to biomagnify (NEPC, 2013b).

7.1 Procedure for preliminary secondary poisoning assessment

All of the organic compounds that were detected in the MWOO solid material underwent a preliminary screen for secondary poisoning. To do this, the following two factors were considered:

1. Frequency of detection – A compound was only highlighted as being potentially relevant for secondary poisoning if it was detected in > 20% of the samples. This value was selected to be conservative but also based on the assumption that for a compound to be relevant for secondary poisoning it would need to be consistently present in the material, rather than only present as hot spots.
2. Log Kow – A compound was only highlighted as being relevant for secondary poisoning if the log Kow was ≥ 4. This value was selected based on guidance provided in the NEPM (NEPC, 2013c). The primary source used to obtain the log Kow values was the Risk Assessment Information System (RAIS) (https://rais.ornl.gov/). Cases where this source was not used have been identified.

It is important to note that this preliminary assessment only identifies compounds in MWOO that have the potential to biomagnify. To determine if secondary poisoning is actually a concern, appropriate exposure concentrations would need to be derived based on the concentrations of the individual compounds in the MWOO. This detailed secondary poisoning assessment is out of scope of this project but should be considered in any future risks assessment work.

7.2 Outcomes of the preliminary secondary poisoning assessment

There were 33 compounds (or groups of compounds) considered in the preliminary secondary poisoning assessment (Table 8). Of these, only 8 compounds (or groups of compounds) satisfied the two criteria outlined above (frequency of detection > 20% and log Kow ≥ 4). This included the PAH compounds phenanthrene and pyrene, the plasticisers DEHA, DEHP and dibutyl phthalate, the alkylphenols 4OP and 4NP, and PBDEs. These are therefore the compounds that are most likely to biomagnify following land application of MWOO. It is recommended that in future risk assessment work, these compounds are assessed for their potential to result in secondary poisoning. Secondary poisoning will not be considered further in this report.

Table 8: List of organic compounds detected in the MWOO, their frequency of detection, log Kow and potential to biomagnify

Compound	Frequency of detection (%)	Log Kow	Potential to biomagnify
Acenaphthene	2.4	3.92	no
Fluoranthene	17	5.16	no
Fluorene	2.4	4.18	no
Naphthalene	72	3.30	no
Phenanthrene	63	4.46	**yes**
Pyrene	20	4.88	**yes**
3+4 methylphenol	90	1.94-1.96	no
Phenol	97	1.46	no
Benzyl butyl phthalate	7.5	4.48[a]	no
DEHA	94	6.11	**yes**
DEHP	100	7.60	**yes**
Dibutyl phthalate	63	4.50	**yes**
Diethyl phthalate	7.5	2.42	no
Dimethyl phthalate	7.5	1.60	no
di-n-octyl phthalate	5.0	8.10[b]	no
Atrazine	3.4	2.61	no
Bifenthrin	16	6.00[c]	no
Endosulfan I	1.0	3.83	no
Fipronil	11	4.0[d]	no
Gamma chlordane	1.0	6.22	no
Metalaxyl	4.5	1.65	no
Prometryn	2.5	3.51	no

Compound	Frequency of detection (%)	Log Kow	Potential to biomagnify
Thiabendazole	81	2.47	no
Trans-permethrin	11	6.50	no
2,4,5-T	1.1	3.31	no
2,4-D	4.3	2.81	no
Dicamba	65	2.21	no
MCPA	81	3.25	no
MCPP	80	3.13	no
4OP	36	4.12[e]	**yes**
4NP	100	4.48[f]	**yes**
BPA	100	3.32	no
PBDEs	100	5.08-8.70[g]	**yes**

[a] EU (2007); [b] from the US Department of Health & Human Services, National Toxicology Program website (http://tools.niehs.nih.gov/cebs3/ntpviews/index.cfm?action=testarticle.properties&cas_number=117-84-0); [c] ATSDR (2003); [d] from the ECHA database (http://echa.europa.eu/); [e] UK EA (2005) [f] EU (2002); [g] Wania & Dungani (2003)

Part III: Hazard assessment and data quality assessment

Section Summary

Part III of this report presents a more detailed hazard assessment and data quality assessment for the chemicals that were identified as requiring further assessment following the preliminary screen. For each of the receptors (solids - ecological and human; leachates - ecological, human, livestock and irrigation), the following were considered:

1. The maximum exceedance of the criteria concentration – quantified as a maximum hazard quotient (HQ_{max}) (calculated from the 95th percentile for the solids data and the maximum concentration for the leachates)
2. The proportion of measured concentrations that exceed the criteria concentration – quantified as a percentage of concentrations with HQ values > 1
3. The reliability of the criteria concentrations
4. The data variability and confidence of chemical concentrations measured in the laboratory.

These four factors were considered together using a scoring system to assign each chemical a priority group (high, medium or low) for each receptor exposed to the MWOO solids or leachates.

The HQ_{max} values for the solid material (based on the 95th percentiles) ranged from 0.12 to 715 and for the leachates (based on the maximums) ranged from 1.1 to 52000. This shows that in some cases very extensive dilution or attenuation would be required to reduce the maximum concentrations to a low and acceptable level, even considering the conservative assumptions built into calculating the HQ_{max}.

For each chemical, the proportion of measured concentrations that exceeded the corresponding criteria concentration ranged from 0.8 to 100%. For ecological receptors exposed to leachates, 28 of the 32 chemicals assessed were found to exceed the criteria concentration in 100% of the samples tested. The percentage of exceedances for each chemical was used to assign a score between 1 and 10, which contributed to the final prioritisation of the chemicals.

The hazard quotient approach used in this assessment is dependent on criteria concentrations that can be compared against the measured concentrations. The criteria concentrations used were generally guideline values that were obtained from a range of sources, from Australia and overseas. These sources used different techniques to derive the guideline values with differing levels of reliability. This has an influence on the uncertainty of the overall assessment. An evaluation of each of the sources was conducted and for each chemical the criteria concentrations were categorised as being of high, moderate or low reliability.

The final factor that was considered was the data variability and confidence of the measured concentrations. This was quantified for both the solid and leachate data by calculating values for relative standard deviation and relative standard error. Generally, the variability in the concentration data for the solid material was considerably higher than that observed for the leachates. This high variability was driven primarily by infrequent samples that had concentrations that were considerably higher than the majority of samples. The relative standard errors, which quantify variability and confidence in the data by taking into account the data variability and the number of samples, were used as part of the final prioritisation of the chemicals.

Each of the above factors were considered together to determine a priority group for each chemical (high, medium or low) for each receptor exposed to the MWOO solids and leachates. The chemicals were considered high priority if HQ_{max} was > 100 or if HQ_{max} was > 10 and 100% of samples had an HQ > 1. The medium and low priority chemicals were then determine by summing scores based on the % of samples with HQ > 1, the reliability of the criteria concentration and the data variability/confidence. The high priority chemicals (or groups of chemicals) from this process are shown in Table 9. The high priority chemicals are considered in a more realistic assessment in Part IV, by calculating soil concentrations at different application rates and soil porewater concentrations at also at the same application rates. The chemical priority groupings identified in this Part of the report can be used to guide further assessment and future research to evaluate the potential risks posed to the environment and human health from land applied MWOO. The possible mitigating factors that may reduce the risk posed by the high priority chemicals are discussed in Part V.

Table 9: Summary of high priority chemicals following the hazard assessment and data quality assessment

Solid material		Leachates			
Ecological	Human health	Ecological	Human health	Livestock drinking water	Irrigation water
Aluminium	PBDEs	Aluminium	Antimony	Copper	Copper
Copper		Barium	Arsenic		Iron
Manganese		Cadmium	Cadmium		Manganese
Zinc		Chromium	Lead		Molybdenum
Phenol		Cobalt	Nickel		Nickel
Bis-2-ethylhexyl adipate		Copper			Dicamba
Bis-2-ethylhexyl phthalate		Iron			Phosphorus
Dibutyl phthalate		Lead			Electrical conductivity
Bisphenol A		Mercury			
Dibutyl tin		Nickel			
Penta-BDE		Tin			
Electrical conductivity		Zinc			
		Sulfate			
		Sulfide			
		MCPA			
		Total ammonia			
		Nitrate (stressor)			
		Total phosphorus (stressor)			
		Free reactive phosphorus (stressor)			
		Electrical conductivity (stressor)			
		Ammonium (stressor)			

8 Introduction

Part III focuses only on the chemicals (or groups of chemicals) that were identified as needing further assessment following the preliminary screen presented in Part II. To do this, a detailed hazard assessment and data quality assessment was conducted. The hazard assessment component used the hazard quotient (HQ) approach, which quantifies the exceedance of a concentration past a criteria concentration. HQs were calculated as the ratio of the measured concentrations in the solids or leachates to the criteria concentrations, considering the six receptors. A maximum HQ value (HQ_{max}) was calculated (either from the 95th percentile concentration or the maximum concentration), along with the proportion of measured concentrations in the solids and leachates with an $HQ > 1$. It is important to note that this type of assessment does not consider combined effects of co-occurring chemicals.

This Part also provides an assessment of the reliability of the criteria concentrations used to derive the HQs and discusses the data variability and confidence in the measured concentrations. Finally, these four pieces of information (HQ_{max}, proportion of HQs >1, reliability of the criteria concentration and data variability/confidence) were used to place each of the chemicals (or groups of chemicals) into priority groups (high, medium or low) under the different receptors for the MWOO solids and leachates. This was done using a scoring and ranking system. These priority groups can be used to guide further risk assessment and/or research investigating the potential risks posed to the environment and human health following land application of MWOO.

9 Hazard assessment

9.1 Calculation of hazard quotients

The HQ approach was used in this study to quantify the exceedance of each chemical past a criteria concentration. The criteria concentrations used were the same as those used for the preliminary screening assessment (Table 6 and Table 7). The HQ gives an indication of the magnitude of the exceedance and a higher value represents a greater potential concern. The magnitude of the HQ gives an estimate of the dilution or attenuation that would be required to reduce the concern to negligible (i.e. HQ < 1). For example, if a chemical produces an HQ of 10, then a 10-fold reduction of the concentration would reduce the HQ to less than 1. For each measured concentration of a chemical, an HQ was calculated as follows:

$$HQ = \frac{measured\ concentration}{criteria\ concentration}$$

The HQ values from each receptor exposed to the MWOO solids and leachates are summarised in Figure 12 to Figure 17. The solid line indicates where the HQ equals 1 (i.e. concentration is equal to the criteria concentration). All of the measured concentrations below the line are considered to be of negligible concern for the receptor being considered. In cases where the measured concentrations were below the LOQ, the LOQ was used to calculate the HQ. This means that when then LOQ was higher than the criteria concentration, all resulting HQ values are greater than 1. This is likely to overestimate the HQ value, however, it is the most conservative assessment of the data. These instances are indicated in the figures with an asterisk and this needs to be considered when interpreting the results.

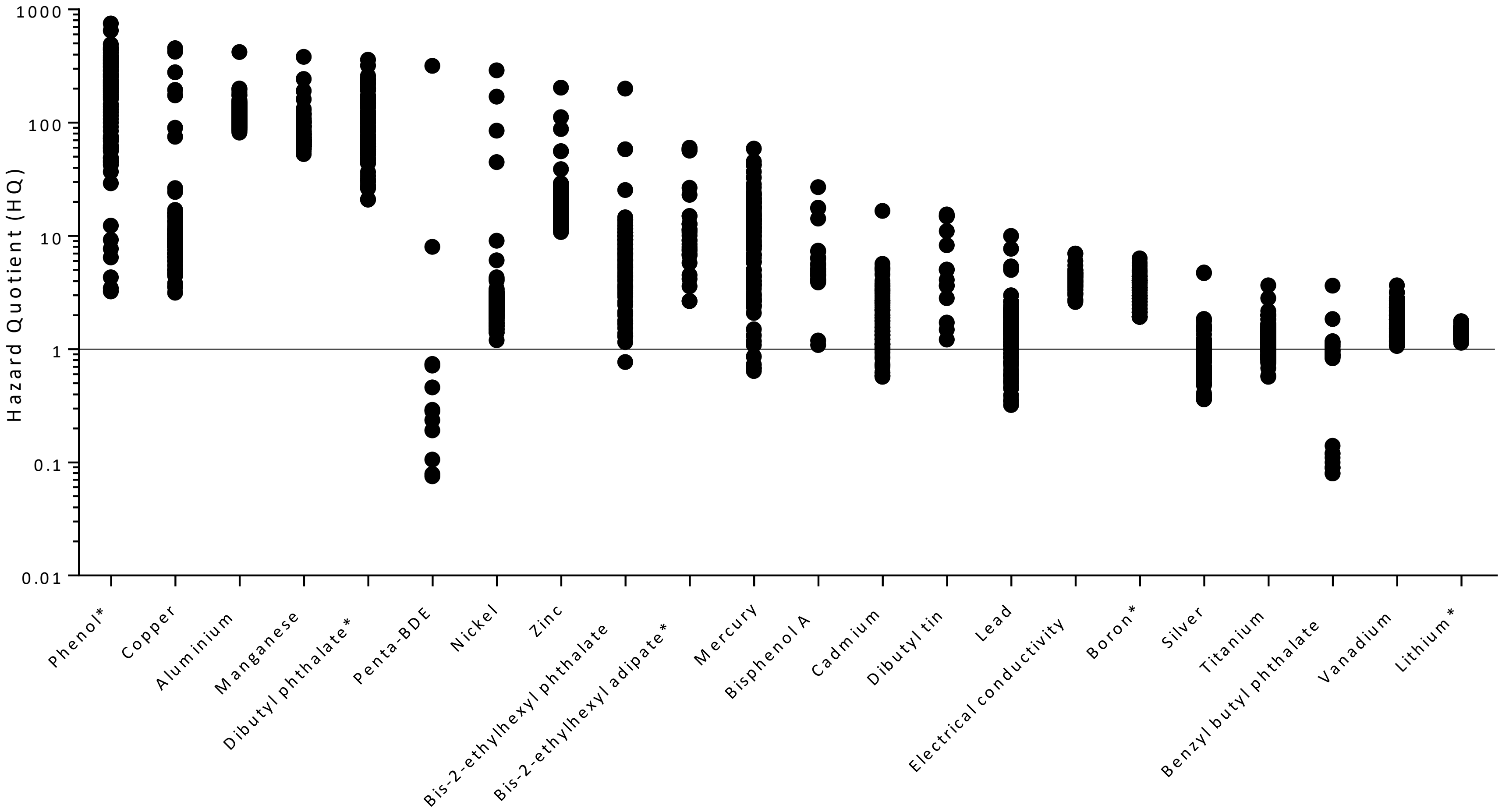


Figure 12: Distribution of hazard quotient (HQ) values from ecological exposure to MWOO solid material. The asterisk (*) indicates chemicals that had quantification limits higher than the corresponding criteria concentration.

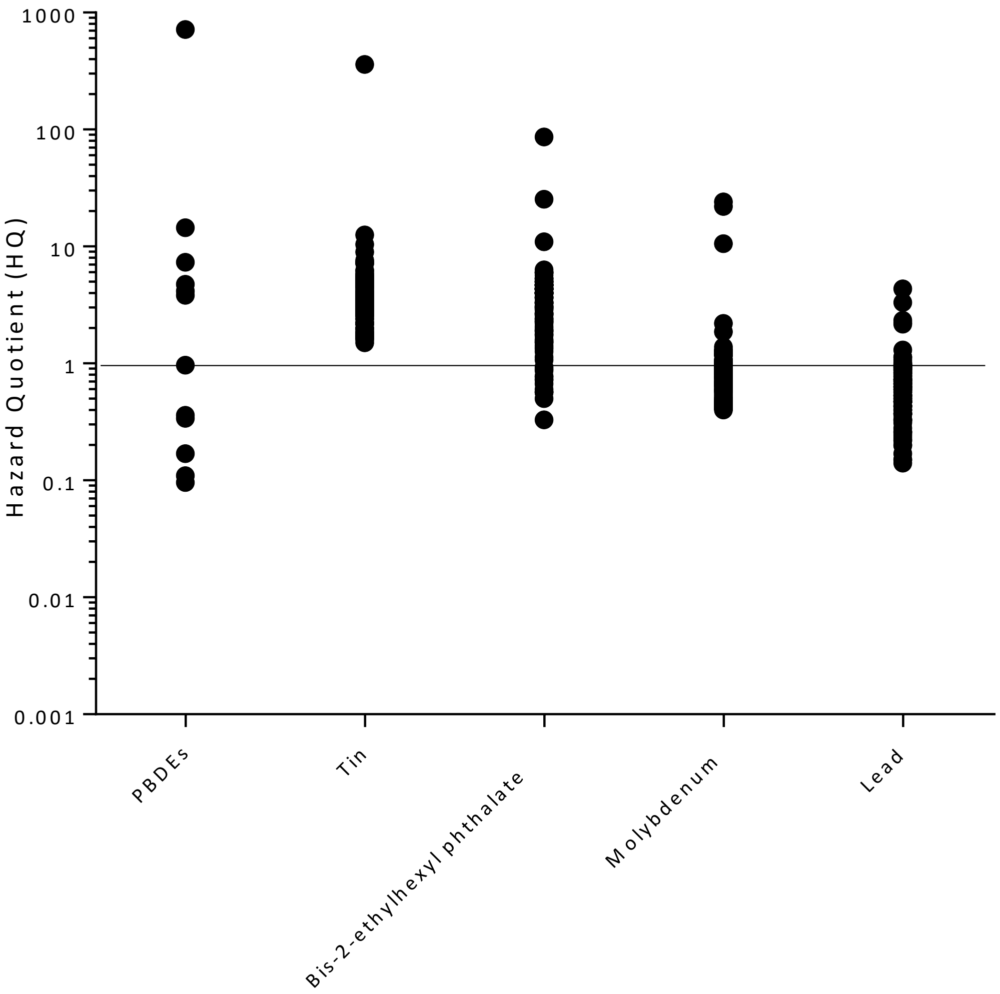


Figure 13: Distribution of hazard quotient (HQ) values from human exposure to MWOO solid material.

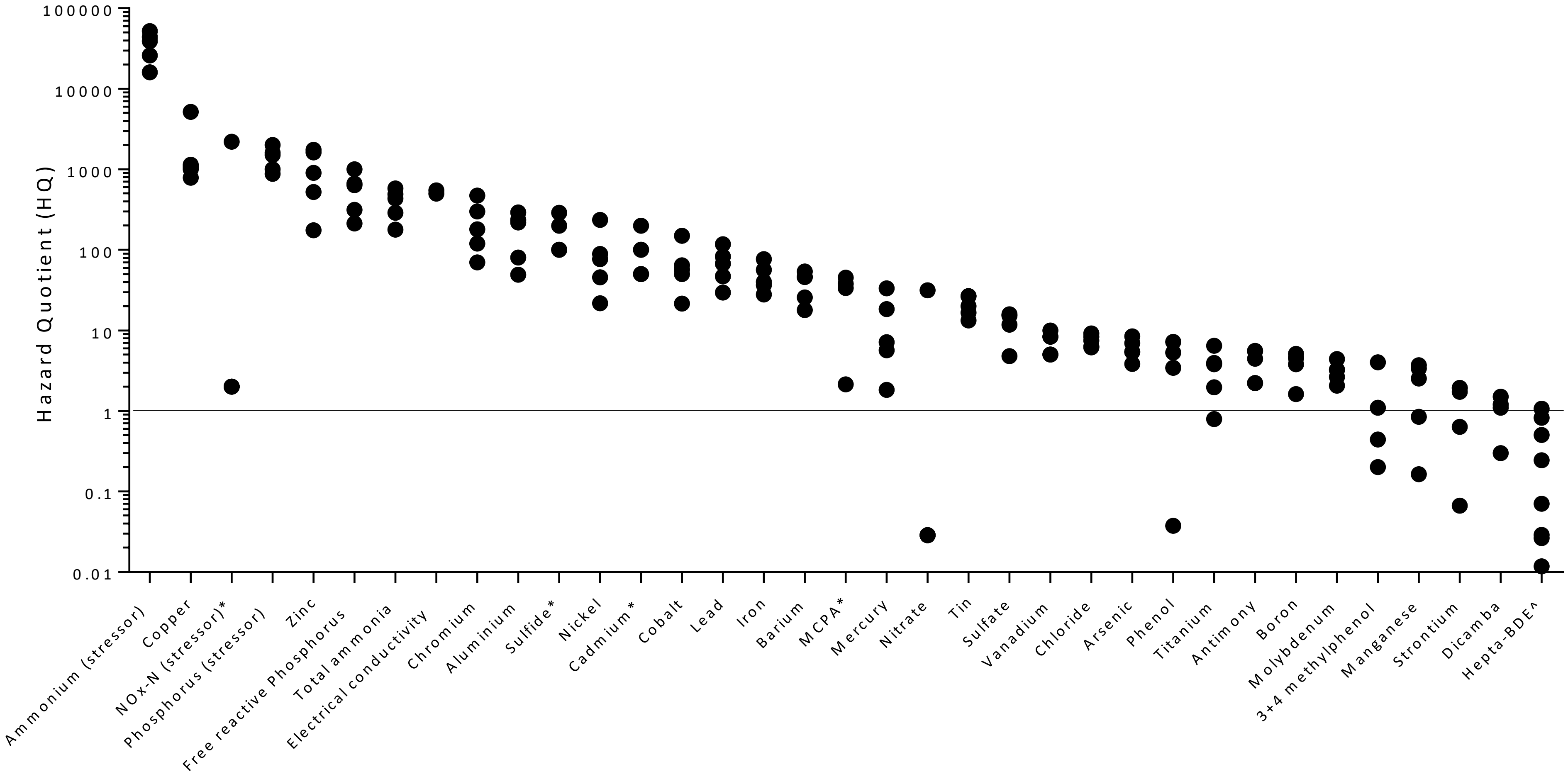


Figure 14: Distribution of hazard quotient (HQ) values from ecological exposure to MWOO leachates. The asterisk (*) indicates chemicals with quantification limits higher than the criteria concentration. ^ PBDE data was from batch extractions and the sum of hepta-BDE used half of the LOQ if congeners were < LOQ

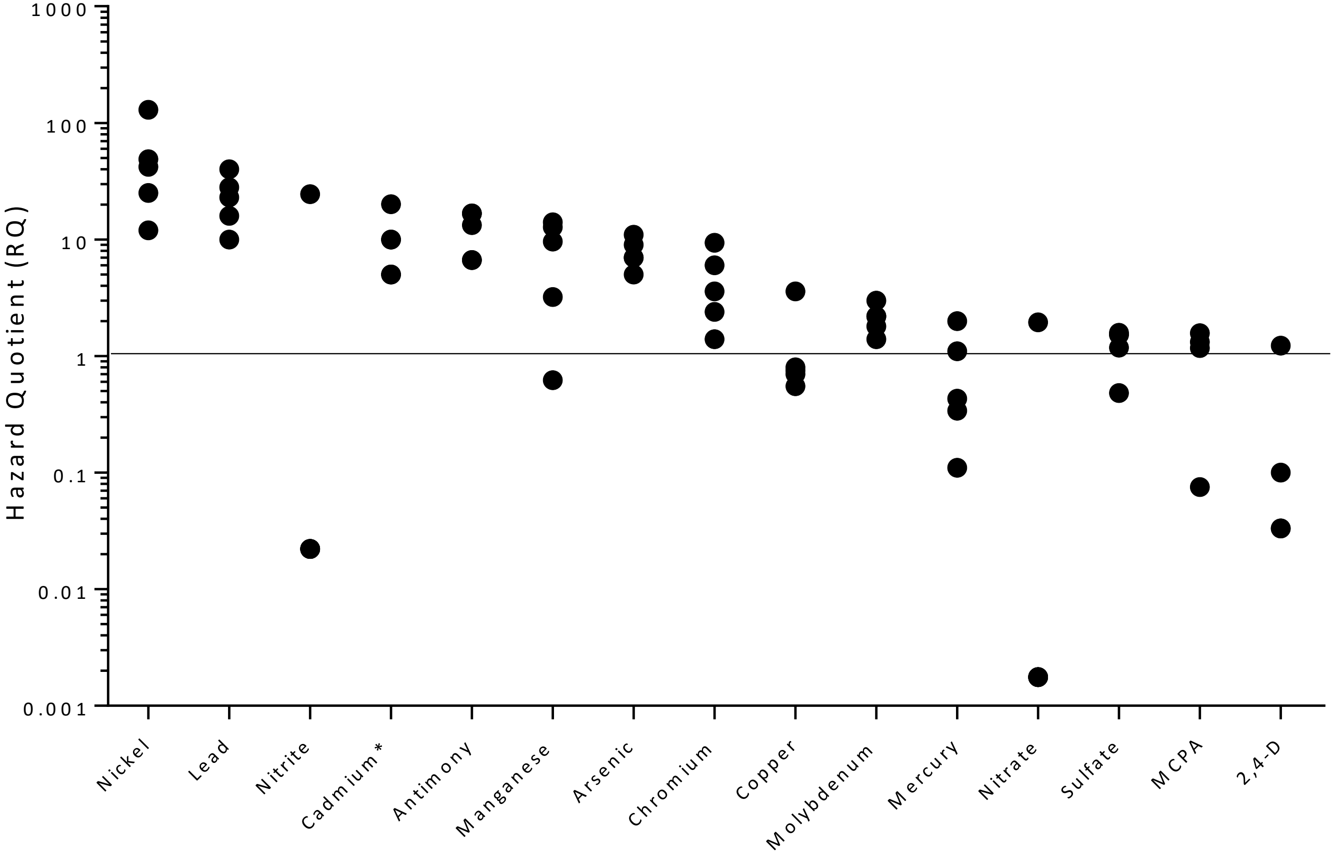


Figure 15: Distribution of hazard quotient (HQ) values from human exposure to MWOO leachates via drinking water. The asterisk (*) indicates chemicals that had quantification limits higher than the corresponding criteria concentration.

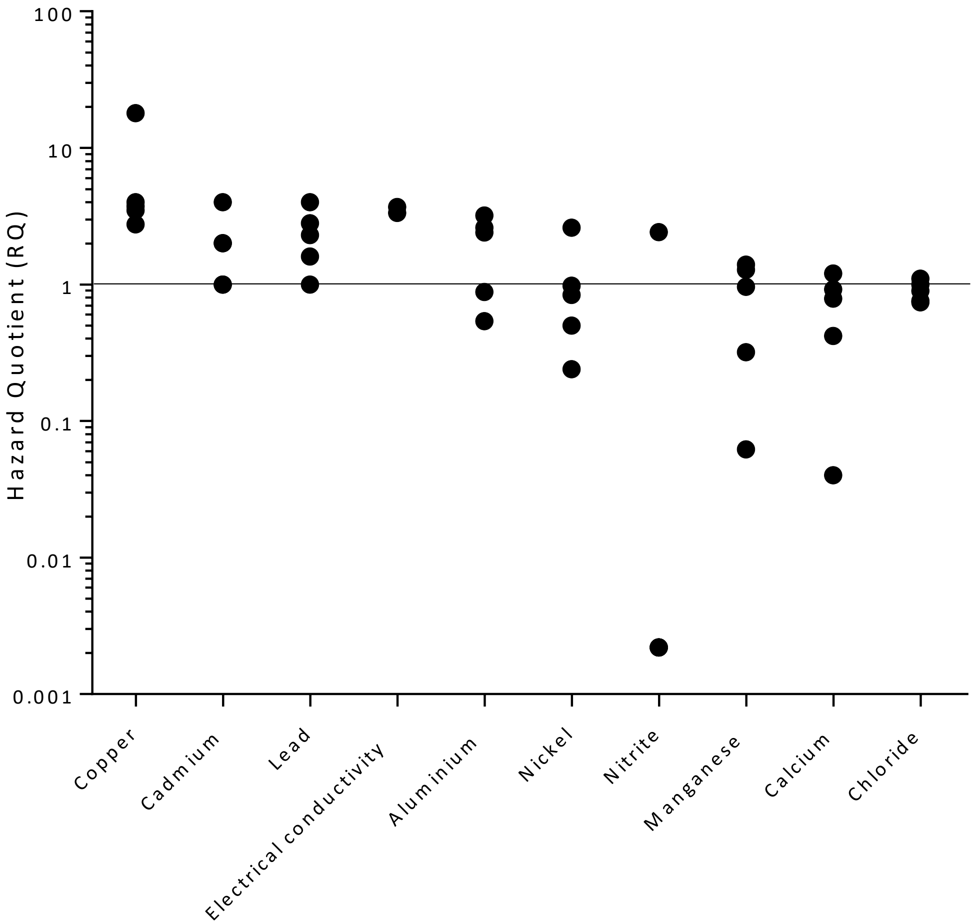


Figure 16: Distribution of hazard quotient (HQ) values from agricultural exposure to MWOO leachates via livestock drinking water.

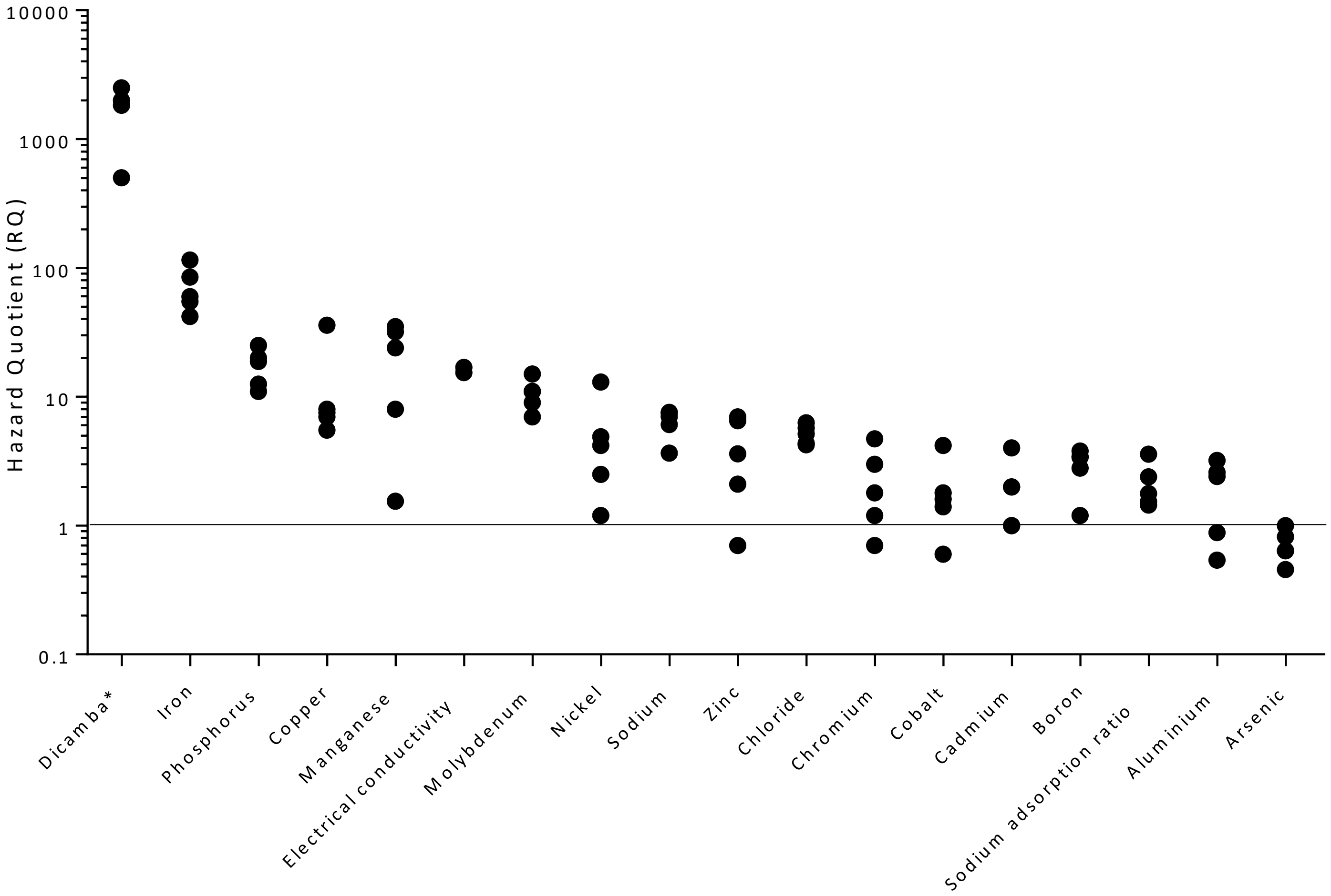


Figure 17: Distribution of hazard quotient (HQ) values from agricultural exposure to MWOO leachates via irrigation water. The asterisk (*) indicates chemicals that had quantification limits higher than the corresponding criteria concentration.

To assist in determining the high priority chemicals, the HQ values were considered in two ways for each receptor and pathway (Table 10).

1. The maximum HQ (HQ_{max}), which gives an indication of the maximum risk posed. For the chemicals in the solid material the 95th percentile concentration was used to calculate the HQ_{max} to remove the influence of very infrequent high concentrations (refer to Section 11.2.1). The only exception to this was for commercial penta-BDE and total PBDEs where the number of samples was small (n = 12) and the variation was high, which meant that there would be large error in the 95th percentile concentration. In this case the maximum concentration in the solid material was used to calculate the HQ_{max}. For the leachate data, the maximum concentrations was also used to calculate the HQ_{max} due to the small number of samples sample (n = 2 to 12).
2. The proportion of all measured concentrations that exceeded the criteria concentration (i.e. HQ > 1).

Table 10: Summary of HQ_{max} values and percentages of HQs exceeding the criteria concentrations (HQ > 1) for all receptors and pathways

Receptor/pathway	Chemical	HQ_{max}*	% exceeding HQ = 1
Ecological solids	Aluminium	169	100
	Boron	4.9	100
	Cadmium	4.4	82
	Copper	60	100
	Lead	2.6	72
	Lithium	1.6	100
	Manganese	120	100
	Mercury	28	96
	Nickel	4.3	100
	Silver	1.6	24
	Titanium	2.0	70
	Vanadium	2.8	100
	Zinc	29	100
	Phenol	461	100
	Benzyl butyl phthalate	1.2	28
	DEHA	59	100
	DEHP	14	100
	Dibutyl phthalate	240	100
	BPA	18	100
	Dibutyl tin	15	100
	Penta-BDE (commercial)	305	17

Receptor/pathway	Chemical	HQ_{max}*	% exceeding HQ = 1
	EC	6.8	100
Human solids	Lead	1.2	7.8
	Molybdenum	1.3	18
	Tin	7.2	100
	DEHP	6.0	89
	PBDEs	715	50
Ecological leachates	Aluminium	290	100
	Antimony	5.6	100
	Arsenic	8.5	100
	Barium	54	100
	Boron	5.1	100
	Cadmium	200	100
	Chromium	470	100
	Cobalt	150	100
	Copper	5140	100
	Iron	77	100
	Lead	118	100
	Manganese	3.7	60
	Mercury	33	100
	Molybdenum	4.4	100
	Nickel	236	100
	Strontium	1.9	60
	Tin	27	100
	Titanium	6.4	80
	Vanadium	10	100
	Zinc	1750	100
	Chloride	9.2	100
	Sulfate	16	100
	Sulfide	290	100
	3+4 methylphenol	4.0	50
	Phenol	7.2	75
	Dicamba	1.5	75
	Hepta-BDE	1.1	13
	MCPA	45	100
	Total ammonia	489	100
	NOx-N (as nitrate)	31	25
	NOx-N (stressor)	2200	100
	Total phosphorus (stressor)	2000	100

Receptor/pathway	Chemical	HQ_{max}*	% exceeding HQ = 1
	FRP (stressor)	1000	100
	EC (stressor)	550	100
	Ammonium (stressor)	52000	100
Human leachates	Antimony	17	100
	Arsenic	11	100
	Cadmium	20	100
	Chromium	9.4	100
	Copper	3.6	20
	Lead	40	100
	Manganese	14	80
	Mercury	2.0	40
	Molybdenum	3.0	100
	Nickel	130	100
	Sulfate	1.6	80
	2,4-D	1.2	25
	MCPA	1.6	75
	Nitrate	1.9	20
	Nitrite	24	20
Stock drinking water	Aluminium	3.2	20
	Cadmium	4.0	60
	Copper	18	100
	Lead	4.0	100
	Manganese	1.4	40
	Nickel	2.6	20
	Calcium	1.2	20
	Chloride	1.1	40
	Nitrite	2.4	20
	EC	3.7	100
Irrigation water	Aluminium	3.2	60
	Arsenic	1.0	20
	Boron	3.8	100
	Cadmium	4.0	100
	Chromium	4.7	80
	Cobalt	4.2	80
	Copper	36	100
	Iron	115	100
	Manganese	35	100
	Molybdenum	15	100

Receptor/pathway	Chemical	HQ_{max}*	% exceeding HQ = 1
	Nickel	13	100
	Zinc	7.0	80
	Sodium	7.6	100
	Chloride	6.3	100
	Dicamba	2500	100
	Phosphorus	25	100
	EC	17	100
	Sodium adsorption ratio	3.6	100

* calculated from the 95th percentiles for exposure to solids pathways (ecological and human), except for commercial penta-BDE (ecological) and PBDEs (human)

9.2 Summary of hazard assessment data

9.2.1 Ecological exposure to solid material

For ecological receptors exposed to the solid material, phenol produced the highest HQ_{max} value of 461 (Table 10). There were also a number of chemicals that had HQ_{max} values greater than 100 including, aluminium, manganese, dibuytl phthalate and commercial penta-BDE. . In contrast, there were a number of chemicals that had HQ_{max} values that were less than 2, , indicating that they showed a small exceedance past the criteria concentration. These chemicals included lithium, silver and benzyl butyl phthalate.

Of the 22 chemicals that were considered, 15 were found to exceed to the criteria concentration in 100% of the samples analysed (i.e. all HQs > 1) (Table 10 and Figure 12). Of these chemicals, five had detection limits that were greater than the corresponding criteria concentration, meaning that HQ values less than 1 were not possible in these cases. For all of the remaining chemicals, the HQ values were distributed above and below HQ = 1, indicating that for some measured concentrations the risk posed would be considered low and acceptable. Some of these chemicals were found to have less than 5% of the measured concentrations greater than the criteria concentrations, including, chromium, molybdenum, tin, antimony, cobalt, strontium and barium.

9.2.2 Human exposure to solid material

There were only 5 chemicals considered in the hazard assessment for the exposure of human receptors to the solid material, based on the outcomes from the preliminary screening assessment (Figure 13). The PBDE compounds (considered as a group) were found to have the highest HQ_{max} value of 715 (Table 10). It is important to note that the criteria concentration for this group of compounds only considers PBDE compounds in the Br1 to Br9 range (NEPC, 2013a) (i.e. excludes the fully brominated deca-BDE). For the assessment shown here, deca-BDE (Br10) has also been included, as this compound is known to degrade to the lower brominated congeners. The removal of deca-BDE (Br10) from the sample with the highest PBDE concentration still yields an HQ value of approximately 700, indicating it is still considerably higher than the criteria concentration. In contrast to the PBDEs which produced the highest HQ_{max} value, lead and molybdenum had HQ_{max} values that were less than 2 , indicating only a minor exceedance past the criteria concentrations.

Tin, which produced the second highest HQ_{max} value (HQ_{max} = 8.3), was the only chemical that had 100% of the measured chemical concentrations that exceeded the criteria concentration (i.e. all HQ values > 1) (Table 10 and Figure 13). It should be noted, however, that the criteria concentration for tin is considered to only be of moderate reliability (see Section 10.2). All of the remaining chemicals that were considered for this exposure scenario had less than 100% of measured concentrations that exceeded the corresponding criteria concentration.

The total PBDE concentrations were found to exceed the criteria concentration in 50% of the samples (Table 10). Interestingly, all of the exceedances were observed from one of the facilities (Facility A), whereas the other facility showed all measured concentrations that were less than the criteria concentration. For Facility A, the HQ values all ranged from 3.8 to 720, whereas, for Facility B they ranged from 0.1 to 1. It is unknown why this would be the case, however, it is likely due to differences in feedstock material, differences in treatment and processing procedures between the two facilities and/or the presence of plastics in the final material that are known to contain PBDEs.

9.2.3 Ecological exposure to leachates

The hazard assessment for the aquatic ecological receptors exposed to the MWOO leachates considered 33 chemicals, based on the outcomes from the preliminary screening assessment (Part II). This included some chemicals, predominately nutrients, which were assessed twice, as they were considered to be stressors as well as toxicants (Figure 14). Due to the comparatively low criteria concentrations for the stressors, these chemicals generally produced the highest HQ_{max} values (Table 10). Overall ammonium ($NH4^+$) as a stressor produced the highest HQ_{max} value of 52000. In contrast, when total ammonia was considered based on its toxicity trigger value it produced an HQ_{max} of approximately 600. The chemical that produced the lowest HQ_{max} was the herbicide compound dicamba, which only marginally exceeded the criteria concentration producing an HQ_{max} value of 1.5.

For this receptor, 27 of the 33 chemicals exceeded the corresponding criteria concentration in 100% of the samples tested (Table 10 and Figure 14). In several of these cases, including, NOx-N (stressor), sulfide, cadmium and MCPA, the criteria concentration was less than the corresponding quantification limit, meaning that HQ values < 1 could not be achieved using this approach. Of the 33 chemicals that were assessed, only eight (nitrate, phenol, titanium, 3+4 methylphenol, manganese, strontium, dicamba and hepta-BDE) produced any HQ values that were less than 1.

Total ammonia, EC and sulfide had relatively high HQs compared to the other chemicals assessed, ranging from 100 to 600 (note that ammonia as a stressor had the highest HQ of 52000). This result is consistent with the results previously discussed from the TIE experiments (Part I), indicating that ammonia, EC and sulfide contributed significantly to the aquatic toxicity of the leachates. The detailed hazard assessment for aquatic ecological receptors did show several metals with higher HQ values, for example, copper and zinc that were not identified through the TIE process. This may be due to metal toxicity in the samples being masked by the dominant toxicity of ammonia, sulfide and salinity and/or low bioavailability of these metals in the leachate samples. The bioavailability of metals in the leachate samples will be discussed in more detail in Part V.

9.2.4 Human health exposure to leachates

There were 15 chemicals that were assessed in more detail for the leachate exposure to human receptors (Figure 15). The rationale behind this assessment was the possibility that leachate generated from land where MWOO had been applied could enter groundwater that is accessed from a bore for domestic purposes. Based on this, the criteria concentrations used were drinking water guidelines. The use of water contaminated with MWOO leachates for recreational purposes was not directly assessed, as the drinking water guidelines are protective of human exposure to recreational waters. The chemical that produced the highest HQ_{max} value for this was nickel (HQ_{max} = 130) (Table 10). The two herbicide compounds MCPA and 2,4-D were found to have the lowest HQ_{max} values of the chemicals assessed, which were 1.6 and 1.2, respectively.

Nitrite and nitrate produced HQ_{max} values of 24 and 1.9 (Table 10), respectively, however, these values are likely to be an overestimation. This is because guidelines for these individual chemicals are provided in the ADWG but in the study the combined measure of NOx-N (NO_2^--N + NO_3^--N) was conducted on the leachate samples. For the comparison against the nitrite criteria concentration it was assumed that the entire NOx-N concentration was present as nitrite-N. A similar approach was used for the comparison of nitrate against the criteria concentration. It is not possible to determine the form of nitrogen from the NOx-N analysis, therefore a more accurate estimate is not possible. It is possible however that nitrate-N will be the dominant form of NOx-N in leachates generated in the field due to oxidation of nitrite in the presence of oxygen, however, this as this cannot be confirmed the most conservative assessment was used.

Approximately half of the chemicals had 100% of measured concentrations greater than the corresponding criteria concentration (Table 10 and Figure 15). This included total ammonia, chloride and a range of metals. The remaining chemicals all had concentrations in the leachates that produced HQ values above and below HQ = 1. Cadmium was the only chemical that had a criteria concentration that was less than the corresponding LOQ. Due to this, all HQ values calculated for this chemical were greater than HQ = 1.

9.2.5 Agricultural exposure to leachates (livestock drinking water)

There were 10 chemicals assessed in the hazard assessment for agricultural receptors that considered possible exposure of livestock through their drinking water (Figure 16). This assumes that there is the potential for leachates or run-off from areas that have received MWOO application to enter groundwater or surface water that is used for livestock drinking. Overall, this exposure pathway produced the lowest HQ values of all the pathways considered. The highest HQ_{max} value of 18 was calculated for copper, whereas the lowest HQ_{max} value of 1.1 was calculated for chloride (Table 10).

Copper was the only chemical considered that had 100% of HQ values greater than the criteria concentration (Table 10 and Figure 16). All of the other chemicals had HQ values that were distributed above and below HQ = 1.

9.2.6 Agricultural exposures to leachates (irrigation)

There were 18 chemicals (or parameters) further assessed for the exposure of agricultural receptors to leachates via irrigation water (Figure 17). Of these chemicals, the herbicide compound dicamba produced the highest HQ_{max} value of 2500 (Table 10). This was considerably higher than iron which produced the second highest HQ_{max} value for this scenario of 115. The lowest HQ_{max} value was for arsenic of 1.1.

Over half of the chemicals assessed for this receptor had 100% of their HQ values greater than 1 (Table 10 and Figure 17), indicating that in all cases the measured concentrations exceeded the criteria concentration. There were also six chemicals that had concentrations both above and below the criteria concentrations. Dicamba, which also had the highest HQ_{max} value, had a corresponding criteria concentration that was considerably lower than the LOQ for this compound. Due to this, all of the HQ values for this chemical were greater than HQ = 1. In this instance, the quantification limit was 500-times higher than the criteria concentration, indicating that the lowest HQ possible for this chemical was 500.

10 Reliability of criteria concentrations

The hazard quotient approach outlined in Section 9.1 involves comparison of measured concentrations against criteria concentrations. The criteria concentrations used for this assessment were from a range of sources and therefore were derived using a range of approaches. The different sources and approaches are likely to produce criteria concentrations with differing degrees of reliability. This section discusses the sources of the criteria concentrations for those chemicals highlighted through the preliminary screening assessment.

In all cases, Australian guidelines were used as the preferred source of criteria concentrations. In cases where Australian guidelines were not available, values from international jurisdictions were used. For the ecological receptors (solid and leachate exposures), the final option for selection of a criteria concentration was to obtain ecotoxicity data and apply an assessment factor (details outlined in Section 5.1.1). Each of these options results in criteria concentrations that have different reliabilities. In cases where a low reliability criteria concentration has been used, this creates greater uncertainty in the overall assessment that needs to be considered. This section considers each of the sources that were used to obtain criteria concentrations and allocates them a rating of high, moderate or low reliability.

10.1 Ecological exposure to solid material

The NEPM for the assessment of site contamination was used as the primary source of criteria concentrations to assess the exposure of ecological receptors to the solid MWOO material (NEPC, 2013b). Following this, the sources used were the ECHA PNEC and the CCME SQG_E. The USEPA Eco-SSLs were also used but none of the chemicals that used this source were identified for further assessment following the preliminary screening assessment.. If no concentrations were available from these sources then screening quick reference tables (or SQuiRT tables) were used (National Oceanic and Atmospheric Administration, NOAA) and as a final option, toxicity data was obtained from the literature and a criteria concentration was obtained by applying an assessment factor.

10.1.1 NEPM ecological investigation levels – high reliability

The NEPM ACLs were used as the source of the criteria concentrations for the metals copper, lead, nickel and zinc. For these metals, the SSD approach was used to derive the ACLs. The SSD approach is a statistical method used to calculate a soil concentration that should theoretically protect a specified percentage of species and/or soil processes. The approach uses toxicity data that have been screened for quality. If there are data available of suitable quality for at least five species (or soil processes) from three taxonomic groups (or nutrient groups) then an SSD can be plotted. These are the minimum data requirements for Australia, however, other jurisdictions may have different minimum data requirements. Criteria concentrations from this source were considered to be of high reliability.

10.1.2 ECHA predicted no effect concentrations – high/moderate/low reliability

ECHA report PNECs that have been derived using a range of techniques depending on the number of toxicity data available. The preference and most reliable technique is the statistical extrapolation technique, which uses an SSD approach. To justify this approach, sufficient toxicity data must be available. This technique was used to derive the PNEC values for boron, cadmium, silver and vanadium. In these cases the criteria concentrations were considered to be of high reliability. If sufficient data are not available to use the statistical extrapolation technique, then an assessment factor approach is used. This approach applies an assessment factor to the toxicity data. The magnitude of the assessment factor is determined based on the number of data available. This approach, with an assessment factor of ≤ 50, was used for mercury, titanium, DEHP, dibutyl phthalate, commercial penta-BDE and BPA. In these cases, the criteria concentrations were considered to be of moderate reliability. For some chemicals with very few toxicity data an assessment factor > 1000 has been used to derive PNEC values and in cases where no suitable toxicity data is available, a PNEC has been based on aquatic toxicity data with consideration of individual chemical partitioning coefficients. For the chemicals in this assessment, manganese, phenol and DEHA had PNECs that were derived using assessment factors of > 50 and lithium, benzyl butyl phthalate and DBT used the partitioning coefficient approach. In these cases the criteria concentrations were considered to be of low reliability.

10.1.3 CCME soil quality guidelines (environmental) – moderate reliability

Electrical conductivity was the only parameter that used the CCME SGQ_E values (other chemicals used the CCME SGQ_E for the preliminary assessment, however in all other cases the maximum concentrations did not exceed the criteria concentrations therefore the chemicals were not further assessed in this section). The guideline value for EC is an interim criterion, which is recommended for use until a higher quality criterion becomes available. These interim criteria are considered to be protective of environmental health but are based on experience and professional judgement rather than using a risk-based approach. Due to this, the value used for EC was considered to be of moderate reliability.

10.1.4 Screening Quick Reference Tables (SQuiRTs) – moderate reliability

The SQuiRT tables were used as the source of criteria the concentrations for aluminium. These tables have been compiled by the NOAA and provide screening concentrations for a range of organic and inorganic contaminants in various environmental media. In this instance, the screening concentrations were derived based on plant toxicity data and therefore were considered to be of moderate reliability.

10.1.5 Assessment factor approach – low reliability

The final approach used to derive criteria concentrations for this exposure scenario was an assessment factor approach. To do this, toxicity data were sourced from the literature or ecotoxicology databases and an assessment factor ranging from 10 to 500 was applied to the data (i.e. the criteria concentration divided by the assessment factor). The magnitude of the assessment factor varied depending on the amount of toxicity data available. This approach accounts for uncertainty due to limited data and is consistent with that used in the NEPM for the Assessment of Site Contamination (NEPC, 2013c). This approach was used for 2,4-D, . In this case, the criteria concentration was considered to be of low reliability.

10.2 Human exposure to solid material

There were three sources used to obtain criteria concentrations for human receptors exposed to the MWOO solid material. The primary source was the HILs from the NEPM for the Assessment of Site Contamination. For instances where no NEPM values were available the CCME IRC were used. In one instance (total organotins) the Dutch Intervention Values were used, however, as the criteria concentration was above the maximum concentration, the organotins were not highlighted for further assessment following Part II.

10.2.1NEPM health investigation levels – high reliability

The HILs from the NEPM were used as the source of criteria concentrations for lead and the PBDEs. The HILs are scientific, risk-based guidance levels (or tier 1 criteria) designed for use in the first stage of an assessment of potential risks to human health from chronic exposure to contaminants. The HILs use a range of assumption about possible exposures for four different exposure scenarios. In this study, the HILs corresponding to the Residential A exposure scenario have been used. This was done as farm workers using the material would have considerable exposure to the material and are not protected by the other NEPM land use scenarios. The Residential A scenario also represents the lowest HILs, which are therefore the most conservative. The values have been derived using all available scientific information (to March 2012), including toxicity reference values that are generally based on the known most sensitive significant toxicological effects. Based on this, the NEPM HILs were considered to be of high reliability.

10.2.2CCME interim remediation criteria – moderate reliability

The CCME IRC were used as the source for the criteria concentrations for molybdenum, tin and DEHP. The IRC are considered to be generally protective of human and environmental health and are based on experience and professional judgement and a review of guidelines and criteria from other Canadian jurisdictions. The interim criteria are not effects-based and are recommended for use until effects-based replacements become available. In the instances where the IRC have been used in this study, equivalent effects-based values were not available, or effects-based values have been derived but were higher than the IRC. In these cases, the IRC have been maintained. As these values are not effects-based, they were considered to be of moderate reliability.

10.3 Ecological exposure to leachates

The primary source used to obtain criteria concentrations for aquatic receptors exposed to the leachates was the Australian and New Zealand Water WQGs (ANZECC and ARMCANZ, 2000). In instances where these were not available, the other sources used were the ECHA PNECs, CCME WQGs, British Colombia Ministry of Environment and SQuiRT screening levels.

10.3.1 Australian and New Zealand Water Quality Guidelines – high/moderate/low reliability

The Australian and New Zealand WQGs were used as the source for the criteria concentrations for the vast majority of metals, as well as sulfide, phenol, MCPA, total ammonia, NOx-N and the range of stressors. For the stressors, the trigger values in the WQGs relate to concentrations above or below which degradation of an ecosystem may be experienced, for example, nutrient concentrations that may result in algal blooms. For the other chemicals, the WQG trigger values are toxicity based. With the exception of the stressors, the WQGs indicate if the trigger value listed is of high, moderate or low reliability. The high reliability trigger values were calculated from chronic data using a species sensitivity distribution. The moderate reliability values were also derived using a species sensitivity distribution, however, used short-term acute toxicity data by applying acute-to-chronic conversion factors. The low reliability trigger values were derived in the absence of a dataset of sufficient quality, and used the assessment factor approach. For all of these cases, the reliability as specified in the WQGs has been used for this assessment.

The trigger values for the stressors were derived using the statistical distribution of reference data collected from five geographical regions across Australia and New Zealand. Following this, the 80th and/or 20th percentile of the reference data was then used to derive trigger values. It should be noted that these are considered to be ‘default’ trigger values and for a real system the recommendation is to derive site specific trigger values using the same approach. Based on this, the trigger values for stressors were considered to be of moderate reliability.

10.3.2 ECHA predicted no effect concentrations – moderate/low reliability

The ECHA PNECs were used as the source of the criteria concentrations for titanium and 3+4 methylphenol. As discussed in Section 10.1.2, the PNECs are derived using a range of methods depending on the number of toxicity data available. For both titanium and 3+4 methylphenol the PNECs were derived using an assessment factor approach. The assessment factor for 3+4 methylphenol was ≤ 50, therefore this criteria concentration was considered to be of moderate reliability. In contrast, the assessment factor used for titanium was > 50, therefore this criteria concentration was considered to be of low reliability.

10.3.3 CCME water quality guidelines – high/moderate reliability

The CCME WQGs were used as the source for the criteria concentrations for chloride and dicamba. The derivation of the guideline value for chloride used a statistical approach. Based on this, the CCME WGQ used for chloride was considered to be of high reliability. There was not sufficient toxicity data available to use a statistical approach to derive the guideline value for dicamba, therefore the assessment factor approach was used (assessment factor = 10). Based on this, the reliability of the CCME WQG for dicamba was considered to be of moderate reliability.

10.3.4 Canadian Federal Environmental Quality Guidelines – moderate reliability

The Canadian Federal Environmental Quality Guidelines provide benchmarks for the quality of the ambient environment. These guidelines were used for hepta-BDE. The values are based on the toxicological effects or hazards of specific substances. When the guidelines are met there is a low likelihood of adverse effects. For this compound, the guideline value was derived using the lowest toxicity data and applying and assessment for of 100 (10 to account for extrapolation from laboratory to field and 10 because PBDEs are persistent and bioaccumulative). Based on this, the guidelines for hepta-BDE are considered to be of moderate reliability.

10.3.5 Screening Quick Reference Tables (SQuiRTs) – moderate reliability

The SQuiRT table (Section 10.1.4) were used to obtain criteria concentrations for barium and strontium. These are screening values from sources in the US and were considered to be of moderate reliability for this assessment.

10.3.6 British Columbia Ministry of Environment ambient water quality guideline – low reliability

The British Columbia Ministry of Environment provides ambient water quality guidelines for the province of British Columbia in Canada. The guideline from this source was used in this assessment for sulfate. These guidelines have been set considering the scientific literature, guidelines from other jurisdictions and general conditions in British Columbia. To account for any uncertainty in the data and to account for laboratory to field differences, safety factors were used which are conservative but reflect natural background conditions in British Columbia. Based on the procedure used to derive these guidelines and their specificity to British Columbia, for this study they were considered to be of low reliability.

10.4 Human exposure to leachates (drinking water)

10.4.1 Australian drinking water guidelines – high reliability

The only source that was used to obtain criteria concentrations for human exposure through drinking water were the ADWGs (NHMRC, 2011). Only guideline values that related to human health were considered and aesthetic considerations were excluded. These guideline values are concentrations that should not result in any significant risk to health of the consumer over a lifetime of consumption and are based on present toxicological knowledge. The ADWGs were considered to be of high reliability.

10.5 Agricultural exposure to leachates (livestock drinking water)

The primary source that was used to obtain criteria concentrations for livestock drinking water was the Australian and New Zealand livestock drinking water quality guidelines (ANZECC and ARMCANZ, 2000). Following this, guidelines from the University of Saskatchewan were used. In the preliminary screening assessment, values from the CCME guidelines for livestock drinking water quality were also used, however, none of the chemicals that used these values were highlighted for further assessment.

10.5.1 Australian and New Zealand livestock drinking water quality guidelines – moderate reliability

The Australian and New Zealand livestock drinking water quality guidelines were used as the source of criteria concentrations for aluminium, cadmium, copper, lead, nickel, calcium, nitrite and EC. In general, these values tend to be based on field observations rather than experimentation. ANZECC and ARMCANZ (2000) states that most of the trigger values for livestock drinking water need further validation and therefore should only be considered as interim guidelines. Due to this, these values were considered to be of moderate reliability.

10.5.2 Guidelines from the University of Saskatchewan – moderate reliability

Guideline values from the University of Saskatchewan (Olkowski, 2009) were used in some cases when Australian and New Zealand Guidelines were not available. This was the case for manganese and chloride. These guidelines have generally been based on observations. Due to this, they were considered to be of moderate reliability.

10.6 Agricultural exposure to leachates (irrigation water)

The primary source used for the criteria concentrations for agricultural exposure to leachates via irrigation water was the Australian and New Zealand water quality guidelines for irrigation. The other source that was used in cases where no Australian and New Zealand values were available was the CCME guidelines for irrigation water.

10.6.1 Australian and New Zealand water quality guidelines for irrigation – high reliability

The Australian and New Zealand water quality guidelines for irrigation were used to obtain criteria concentrations for a range of the metals as well as sodium, chloride, phosphorus, EC and the sodium adsorption ratio. The guidelines were developed to ensure that the quality of natural resources is not degraded, the environment is not irreversibly harmed, and yields and production quality are maintained and improved. They were considered to be of high reliability.

10.6.2 CCME guidelines for irrigation water – moderate reliability

The CCME guidelines for irrigation water were used as the source of a criteria concentration for dicamba. This guideline value was derived based on toxicity data for crops and takes into account irrigation rates and an uncertainty factor. Based on this, the value for dicamba was considered to be of moderate reliability.

11 Data variability and confidence in chemical concentrations

11.1 Procedure for assessing data variability and confidence

The detailed hazard assessment conducted as part of this project also included an evaluation of the variability in the measured concentrations of both the solid material and the leachates. The important pieces of information that are required to understand the variability in concentration data are the mean concentrations, the number of data points (*n*) and the spread of that data. In this study to understand the spread of the data standard deviation was used and to understand the confidence in the data standard error was used.

The standard deviation takes into account the deviation of each sample from the mean and a value close to zero indicates that there is minimal spread of the data about the mean. The standard deviation can be normalised to the mean as the relative standard deviation (RSD), which is the standard deviation as a percentage of the mean. In contrast, the standard error indicates how far the mean is likely to be from the true sample mean and takes into account the standard deviation and the number of samples (*n*). The standard error is always smaller than the standard deviation and is lower with greater number of samples. The standard error is calculated as:

$$SE = \frac{SD}{\sqrt{n}}$$

where SE is the standard error, SD is the standard deviation and *n* is the number of samples. Standard error can also be normalised to the mean and presented as a relative standard error (RSE), which is the standard error as a percentage of the mean.

The RSD and RSE were calculated for each chemical that was highlighted through the preliminary screening assessment in both the solid material and the leachates. In cases where the measured concentration of a chemical was below the quantification limit, the LOQ was used. This has an influence on the SD and SE calculations as it limits the variability at one end of the distribution. This should be considered when interpreting the results.

11.2 Outcomes from data variability and confidence assessment

11.2.1 Concentrations in the solid material

The number of samples for the majority of chemicals in the solid material was 128 (i.e. *n* = 128). This was the case for all of the metals, phenol, DEHP and dibutyl phthalate (Table 11). For the remaining chemicals, the number of samples ranged from 12 for the PBDEs and benzyl butyl phthalate through to 44 for electrical conductivity. There is likely to be more uncertainty around the mean generated for the chemicals from a lower number of samples, compared to the means generated for the chemicals with a larger number of samples.

Table 11 provides a summary of the RSDs and RSEs for the concentration data for each of the chemicals in the solid material. In a number of cases, the RSD values were greater than 200%, indicating highly variable data. This was the case for copper, molybdenum, nickel, tin, and the PBDEs. In all cases where large variability was observed, this was driven by a small number of samples with concentrations considerably greater than the majority of concentrations. This pattern can be observed in Figure 12 to Figure 17, which show the distribution of all the HQ values for each chemical. Although in this figure the actual concentrations are not shown, the relative distributions are the same as all the concentrations have all been standardised relative to the same value (i.e. the criteria concentration). It is important to note however that in Figure 12 to Figure 17 the y-axis is on a log scale meaning that visually the spread of the data is reduced.

This pattern of the concentration data can also be summarised using frequency distribution plots, which display the frequency that each concentration occurs. The frequency distribution plots for copper, nickel, DEHA and total PBDEs in MWOO material are shown in Figure 18 to provide examples of the general pattern in the concentration data observed. These figures show that the majority of concentrations are found at the lower end of the distribution. For copper, most of the measured concentrations were below 500 mg/kg, however several samples had concentrations greater than this up to a maximum concentration of 9100 mg/kg. A similar pattern was observed for nickel where most of the concentrations were below 200 mg/kg, however, the highest concentration was 2900 mg/kg. For the organic compounds shown in Figure 18, DEHA and total PBDEs, the number of samples was much lower than that of the metals (Table 11), however a similar pattern can still be seen. These data show that for most chemicals the variability is high, which is generally driven by the infrequent detection of chemicals at considerably greater concentrations in some samples compared to most of the samples. This is likely due to heterogeneity of the material and possible fragments of contaminated material resulting in occasional elevated concentrations of chemicals. It should also be noted that the mass of material used for the chemical analysis is normally small, for example less than 1 g for the metals analysis, indicating that if the material sampled for analysis contained a fragment of contaminated material it is likely this will produce a considerably higher concentration relative to the other samples.

Table 11: Summary of number of samples, relative standard deviation (%) and relative standard error (%) for chemicals in the solid material

Chemical	Number of samples	Mean (mg/kg)	Relative standard deviation (%)	Relative standard error (%)
Aluminium	128	6100	30	2.6
Boron*	128	18	30	2.7
Cadmium*	128	1.9	85	7.5
Copper	128	440	290	25
Lead	128	210	77	6.8
Lithium*	128	2.5	11	0.96
Manganese	128	290	43	3.8
Mercury	128	0.27	81	7.2
Molybdenum*	128	5.7	260	23
Nickel	128	70	430	38
Silver*	128	1.1	77	6.8
Titanium	128	74	33	2.9
Tin	128	33	480	42
Vanadium	128	11	28	2.5
Zinc	128	570	89	7.9
Phenol*	128	26	74	6.5
Benzyl butyl phthalate*	40	1.3	74	21
DEHA*	33	16	110	18
DEHP	128	124	190	17
Dibutyl phthalate*	128	5.1	64	5.7
BPA	24	26	84	17
Dibutyl tin	14	0.012	79	21
Penta-BDE	12	10	330	96
PBDEs	12	63	330	95
EC	44	4.2 dS/m	23	3.5

* includes samples with concentrations below the quantification limit where the LOQ has been used to calculate mean, RSD and RSE

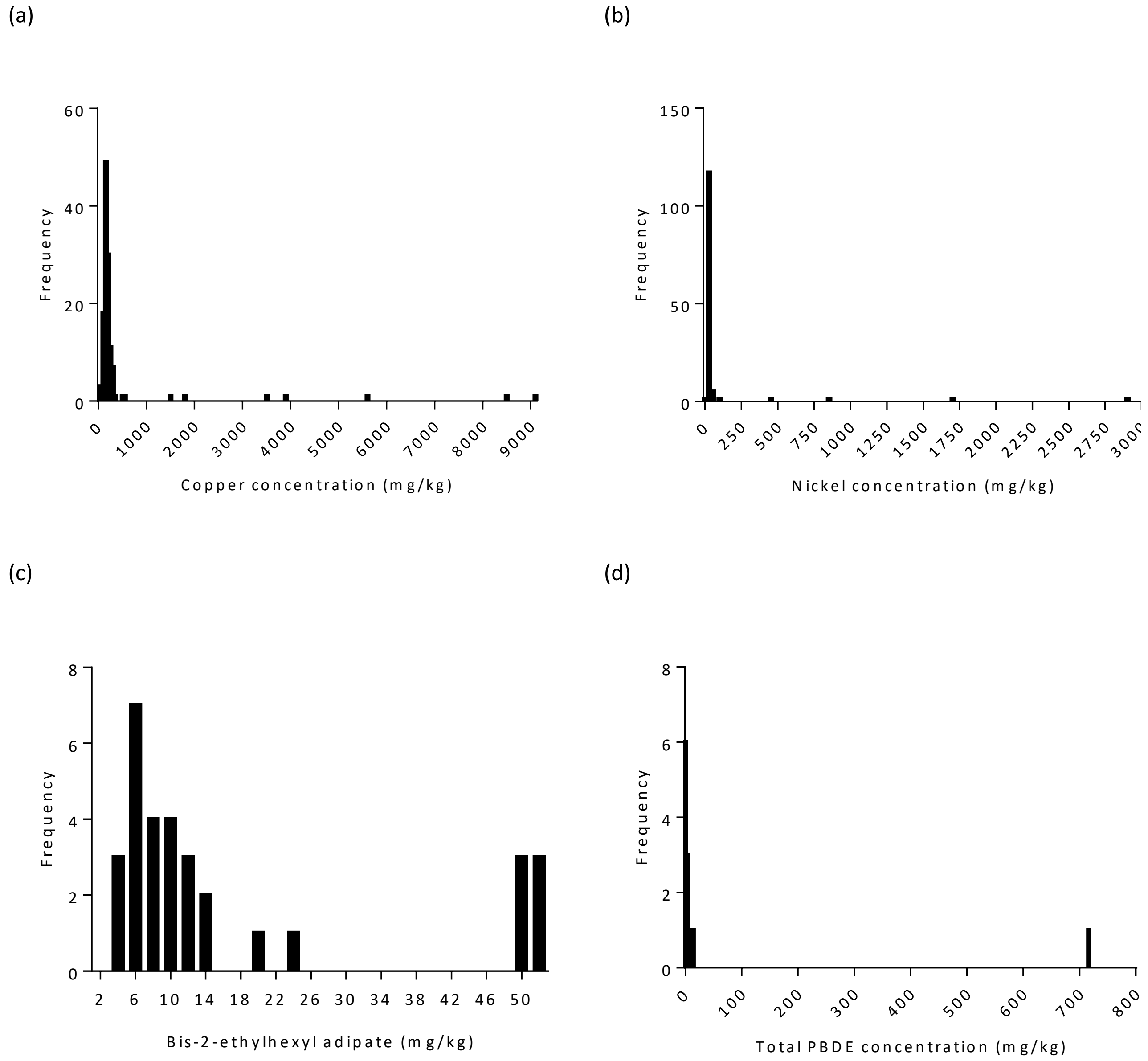


Figure 18: Frequency distribution plots for copper, nickel, bis-2-ethylhexyl adipate (DEHA) and total poly brominated diphenyl ethers (PBDEs) in the solid MWOO material

The RSE values, which are calculated based on the standard deviation and the number of samples, indicate that in some cases there was fairly good confidence that the mean concentration calculated is close to the actual mean concentration of the material. For some chemicals (aluminium, manganese, titanium and vanadium as well as EC) the RSE values were less the 5%, indicating that the true mean is likely to be within 5% of the reported mean. Except for EC, the low RSE is driven by the large number of samples of 128, providing more certainty in the data. In cases where the variability was much greater, the RSE is considerably greater, for example tin which had an RSE of 42. This indicates that there is much more uncertainty around this data. This is again due to the large variability in some of the datasets and the infrequent measurement of some chemicals at concentrations that were considerably higher than in the majority of the samples.

11.2.2 Concentrations in the leachates

There were considerably fewer samples to determine the mean and variability in chemical concentrations in the leachates compared to the solid material. The F1 column leachates were only collected during SE4 and SE5 of the project and as a result there were only 4 to 5 concentration values for each of the chemicals in this fraction. In contrast, the batch extractions of the solid material were conducted during the entire study, therefore, considerably more data are available from this method. Up to this point, the batch extraction data have not been used to assess the risks associated with the leachates, as the F1 fraction produced higher and therefore more conservative values. In this section, to understand the variability in the concentrations of chemicals mobilised from the MWOO, the batch extraction data were used as more data were available (Table 12). The only exceptions to this were sulfide and EC, which used the F1 data in Table 12 because these measurements were not conducted on the batch extraction samples. In addition, as the concentrations of the chemicals were lower in the batch extractions compared to the F1 fractions, in some cases a large proportion of samples showed concentrations below the quantification limit. In cases where fewer than half the samples had concentrations less than the quantification limit, the LOQ was used to calculate the values in Table 12. For arsenic, cadmium, tin, 2,4-D and NOx-N more than half of the samples were below the quantification limit in the batch extractions. In these instances, the results from the F1 fraction have been used to give an estimate of the data variability (these instances have been indicated in Table 12).

Generally the chemical concentrations in the leachates showed less variability than that observed in the solids. This is likely due to the larger sample size that was used for the batch extractions or column leachates (50 g and 300 g, respectively), compared to that used for the chemical analysis (e.g. less than 1 g for metals). The metals copper and nickel showed the greatest variability, as shown by the RSD values, which is consistent with the high variability of the chemicals in the solids. The variability in the NOx-N concentration (shown for the F1 fraction in Table 12), was the greatest of all the chemicals assessed in the leachates. This was because NOx-N was measured in one of the five samples at a concentration of 22 mg/L, whereas in the remaining four samples the concentration was less than the quantification limit of 0.02 mg/L.

The RSE values show that the measurements for chloride and EC are likely to provide the best estimation of the true sample mean. In these cases, the RSE indicates that the true means for chloride and EC are likely to be within 5% of that estimated from these samples. This is likely due to the even distribution of the major ions that contribute to EC (including chloride) throughout the material. This will be facilitated by the mixing that takes place during the treatment of the material and the high water solubility of these ions.

Table 12: Summary of number of samples, relative standard deviation (%) and relative standard error (%) for chemicals in leachates. All data is from the batch extractions unless indicated otherwise.

Chemical	Number of sample	Mean (mg/L)	Relative standard deviation (%)	Relative standard error (%)
Aluminium	17	3.5	53	13
Antimony*	17	0.01	30	7.2
Arsenic^	5	0.08	29	13
Barium*	17	0.06	57	14
Boron	17	0.56	54	13
Cadmium^*	5	0.02	61	27
Chromium	17	0.06	61	15
Cobalt*	17	0.02	61	15
Copper	17	0.64	93	22
Iron	17	4.5	55	13
Lead	17	0.10	53	13
Manganese	17	0.93	62	15
Mercury* (µg/L)	17	0.25	66	16
Molybdenum	17	0.03	37	8.9
Nickel	17	0.28	89	22
Strontium	17	0.31	46	11
Tin^	5	0.06	29	13
Titanium	17	0.05	47	11
Vanadium	17	0.02	41	10
Zinc	17	1.9	67	16
Calcium	17	140	54	13
Sodium	17	200	22	5.3
Chloride	15	200	14	3.7
Sulfate	13	140	37	10
Sulfide^	4	0.17	53	26
3+4 methylphenol	16	0.07	84	21
Phenol*	16	0.31	76	19
Hepta-BDE	8	5.9	120	41
2,4-D^	4	0.01	170	84
Dicamba*	14	0.004	17	4.6
MCPA*	14	0.02	50	13
Total ammonia	15	80	21	5.2
NOx-N^*	5	4.4	220	99

Chemical	Number of sample	Mean (mg/L)	Relative standard deviation (%)	Relative standard error (%)
Phosphorus	17	4.5	49	12
Free Reactive Phosphorus	15	1.7	110	29
EC^ dS/m	2	11	6.7	4.8
SAR	13	4.1	26	7.2

^ variability was calculated using the F1 fraction from the column leachates; * includes samples with concentrations below the quantification limit where the LOQ has been used to calculate mean, RSD and RSE

The frequency distribution plots for select chemicals in the leachates (Figure 19), show a different pattern of results to that observed for the solid material. Although there was a much smaller number of samples, the frequency distribution plots show a more even spread of data across the concentration range. For copper and nickel, which showed the highest variability (based on the RSD values) there were still some measured concentrations that were higher than the majority of measured concentrations as was observed for the solid material. However, the magnitude of this was small compared to that observed in the solid material. In contrast, the chloride and sodium concentrations showed a more even spread of data, which is consistent with the low RSD and RSE values for these chemicals (Table 12). These results show that although the concentrations in the solid material can be highly variable, the variability in the leachates is not that great. This is primarily due to the larger sample size used for the column leachates and batch extractions (300 g and 50 g, respectively). This means however that over a broad scale that there is less uncertainty in the estimate of concentrations that may be present in leachates following land application of MWOO.

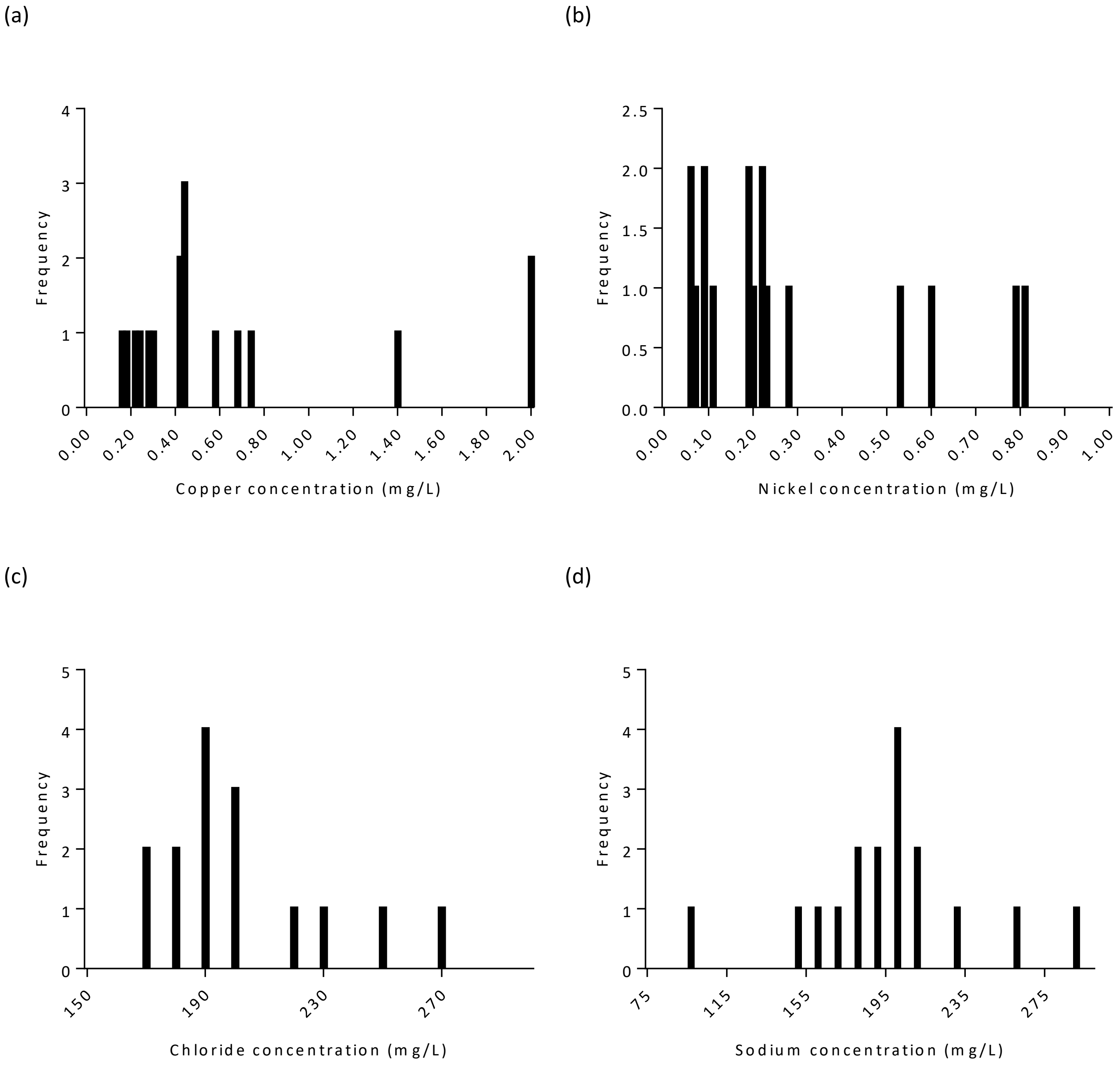


Figure 19: Frequency distribution plots for (a) copper, (b) nickel, (c) chloride and (d) sodium concentrations in the batch extraction samples

12 Final prioritisation of chemicals

12.1 Outline of procedure for prioritisation

This section uses the information presented in Sections 9 to 11 to place each chemical into a priority group (high, medium or low priority) for each receptor to the MWOO solids and leachates. The approach uses the HQ_{max} values, the proportion of exceedances from the criteria concentration (i.e. % of HQs > 1), the reliability of the criteria concentration and the data variability and confidence. The chemicals were categorised or assigned a score within each of these parameters and then based on these, the chemicals were grouped as high, medium or low priority for further assessment. The scoring was designed so that factors that caused greater uncertainty were assigned a high score. Therefore, it was favoured towards avoiding false negatives.

The HQ_{max} values were used to categorise each of the chemicals as follows:

• $HQ_{max} > 1000$	Very high
• $HQ_{max} > 100$ and ≤ 1000	High
• $HQ_{max} > 10$ and ≤ 100	Moderate
• $HQ_{max} > 1$ and ≤ 10	Low

For receptors and sample type (solid material or leachate), each chemical was assigned a score from 1 to 10 based on the percentage of measurements that produced HQ values > 1.

- > 90 and ≤ 100 = 10
- > 80 and ≤ 90 = 9
- > 70 and ≤ 80 = 8
- > 60 and ≤ 70 = 7
- > 50 and ≤ 60 = 6
- > 40 and ≤ 50 = 5
- > 30 and ≤ 40 = 4
- > 20 and ≤ 30 = 3
- > 10 and ≤ 20 = 2
- > 0 and ≤ 10 = 1

The reliability of the criteria concentrations for each chemical were given a score based on the allocation of high, moderate or low reliability described in Section 10:

- High reliability = 1
- Moderate reliability = 3
- Low reliability = 5

Finally the RSE values for each chemical were used to quantify the variability and confidence in the data. The RSE values were used in preference to the RSD values as they take into account the number of samples (*n*) and therefore provide a better indication of the level of confidence in the data. Based on the RSE, a relative score was given to each chemical as follows:

- > 0 and ≤ 5% = 1
- > 5 and ≤ 10% = 2
- > 10 and ≤ 40% = 3
- > 40 and ≤ 70% = 4
- > 70% = 5

This information was then used to assign each of the chemicals for each of the receptors exposed to the MWOO solids and leachates with a priority group for further assessment. This was done as follows:

- High priority if:
    - the HQ_{max} value was > 100 (i.e. high or very high), or
    - the HQ_{max} values was >10 (i.e. moderate) and 100% of samples exceeded the criteria concentration (i.e. all HQs > 1)
- Medium priority if the sum of scores from % exceedances, reliability of criteria concentration and data variability was ≥ 12
- Low priority if the sum of scores from % exceedances, reliability of criteria concentration and data variability was < 12.

The cut-off criteria of 12 between medium and low was selected so that any chemical which had an HQ_{max} > 1 and ≤ 10 (i.e. low HQ_{max}) but was found to exceed the criteria concentration in 100% of the samples would be grouped as medium priority

12.2 Outcomes from chemical prioritisation

Table 13 to Table 18 summarise the information used for the prioritisation of each chemical (or group of chemicals) or other parameter into high, medium or low priority groups for receptors exposed to the MWOO solids and leachates. The ecological receptors, exposed to both to the solids and the leachates resulted in the greatest number of chemicals being categorised as high priority. For the ecological receptors exposed to the solid material, 12 chemicals were found to be high priority. These included metals (aluminium, copper, manganese and zinc), plasticisers (DEHA, DEHP and dibutyl phthalate) and other organic or organo-metallic compounds (phenol, BPA, DBT and commercial penta-BDE). The ecological exposure to the leachates resulted in 21 chemicals (or groups of chemicals) or parameters being high priority. These included a range of metals, sulfate, sulfide, total ammonia and the pesticide MCPA, as well as a range of stressors (nitrate, total phosphorus, free reactive phosphorus, EC and ammonium).

The human exposure to the solid material scenario resulted in only PBDEs being considered as high priority. There were five high priority chemicals for human receptors exposed to leachates, which included only metals (antimony, arsenic, cadmium, lead and nickel). Finally, for livestock exposure to leachates through drinking water only copper was identified as being high priority. The lack of high priority chemicals for livestock drinking water is partly due to a lack of criteria concentrations. When leachates used as agricultural irrigation water was considered, this identified more chemicals as high priority, including, copper, iron, manganese, molybdenum, nickel, dicamba and phosphorus as well as the general characteristic of EC.

It is noted that using this approach, EC was not highlighted as being high priority for the exposure of ecological receptors to the solid material. This was primarily due to the HQ values ranging from 2.6 to 7, meaning that a final high priority category was not possible using the approach outlined above. As the possible magnitude in the range of EC values is not as great as for many of the chemicals (e.g. metal concentrations can vary over orders of magnitude), it is possible that this approach has underestimated the potential ecological risks in the soil at an MWOO land application site. The addition of material to soil with high salt content (up to 14 dS/m in this case), may have both short- and long-term effects on soil health. Due to this, it is recommended that EC be considered as high priority for terrestrial ecological receptors.

The chemical priority groups identified in this section can be used to guide further assessment and future research priorities to better understand the potential risks posed to the environment and human health following land application of MWOO. An additional assessment of the high priority chemicals is presented in Part IV, considering land application rates and soil pore water concentrations, which can be used to support the selected of high priority chemicals. Part V will discuss possible risk mitigating factors in the environment, with a focus on these high priority chemicals. These risk mitigating factors can be used in a detailed risk assessment to derive realistic exposure concentrations for both human and ecological receptors following land application of MWOO.

Table 13: Summary of data used to prioritise chemicals for ecological exposures to solid material. The information used to determine the priority group is shown in bold/underline

Chemical/parameter	HQ_{max}	% HQ > 1		Relative standard error		Reliability of criteria concentration		Sum of scores	Priority group
		value	score	value	score	value	score		
Aluminium	**High**	100	10	2.6	1	Moderate	3	14	High
Boron	Low	100	10	2.7	1	High	1	**12**	Medium
Cadmium	Low	82	9	7.5	2	High	1	**12**	Medium
Copper	**Moderate**	**100**	10	25	3	High	1	14	High
Lead	Low	77	8	6.8	2	High	1	**11**	Low
Lithium	Low	100	10	0.96	1	Low	5	**16**	Medium
Manganese	**High**	100	10	3.8	1	Low	5	16	High
Mercury	Moderate	96	9	7.2	2	Moderate	3	**14**	Medium
Nickel	**Low**	100	10	38	3	High	1	**14**	Medium
Silver	Low	24	3	6.8	2	High	1	**6**	Low
Titanium	Low	73	8	2.9	1	Moderate	3	**12**	Medium
Vanadium	Low	100	10	2.5	1	High	1	**12**	Medium
Zinc	**Moderate**	**100**	10	7.9	2	High	1	13	High
Phenol	**High**	100	10	6.5	2	Low	5	17	High
Benzyl butyl phthalate	Low	28	3	21	3	Low	5	**11**	Low
DEHA	**Moderate**	**100**	10	18	3	Low	5	18	High
DEHP	**Moderate**	**100**	10	16	3	Moderate	3	16	High
Dibutyl phthalate	**High**	100	10	5.7	2	Moderate	3	15	High
BPA	**Moderate**	**100**	10	17	3	Moderate	3	16	High
Dibutyl tin	**Moderate**	**100**	10	21	3	Low	5	18	High
Penta-BDE (commercial)	**High**	17	2	96	5	Moderate	3	10	High
EC	Low	100	10	3.5	1	Moderate	3	14	High*

* EC was considered high risk based on the above discussion in the text

Table 14: Summary of data used to prioritise chemicals for human exposures to solid material. The information used to determine the priority group is shown in bold/underline

Chemical/parameter	HQ_{max}	% HQ > 1		Relative standard error		Reliability of criteria concentration		Sum of scores	Priority group
		value	score	value	score	value	score		
Lead	Low	7.8	1	6.8	2	High	1	**4**	Low
Molybdenum	Low	18	2	23	3	Moderate	3	**8**	Low
Tin	Low	100	10	42	4	Moderate	3	17	Medium
DEHP	Low	89	9	17	3	Moderate	3	**16**	Medium
PBDEs	**High**	50	5	95	5	High	1	11	High

Table 15: Summary of data used to prioritise chemicals for ecological exposures to leachates. The information used to determine the priority group is shown in bold/underline

Chemical/parameter	HQ_{max}	% HQ > 1		Relative standard error		Reliability of criteria concentration		Sum of scores	Priority group
		value	score	value	score	value	score		
Aluminium	**High**	100	10	13	3	Moderate	3	16	High
Antimony	Low	100	10	7.2	2	Low	5	**17**	Medium
Arsenic	Low	100	10	13	3	High	1	**14**	Medium
Barium	**Moderate**	**100**	10	14	3	Moderate	3	16	High
Boron	Low	100	10	13	3	High	1	**14**	Medium
Cadmium	High	100	10	27	3	High	1	14	High
Chromium	**High**	100	10	15	3	Low	5	18	High
Cobalt	**High**	100	10	15	3	Low	5	18	High
Copper	**Very high**	100	10	22	3	High	1	14	High
Iron	**Moderate**	**100**	10	13	3	Low	5	18	High
Lead	**High**	100	10	13	3	High	1	14	High
Manganese	Low	60	6	15	3	Moderate	3	**12**	Medium
Mercury	**Moderate**	**100**	10	16	3	High	1	14	High
Molybdenum	Low	100	10	8.9	2	Low	5	**17**	Medium
Nickel	**High**	100	10	22	3	High	1	14	High
Strontium	Low	60	6	11	3	Moderate	3	**12**	Medium
Tin	**Moderate**	**100**	10	13	3	Low	5	18	High
Titanium	Low	80	8	11	3	Low	5	**16**	Medium
Vanadium	Low	100	10	10	2	Low	5	**17**	Medium
Zinc	**Very high**	100	10	16	3	High	1	14	High
Chloride	Low	100	10	3.7	1	High	1	**12**	Medium
Sulfate	**Moderate**	**100**	10	10	2	Low	5	17	High
Sulfide	**High**	100	10	26	3	Moderate	3	16	High
3+4 methylphenol	**Low**	50	5	21	3	Moderate	3	**11**	Low
Phenol	Low	75	8	19	3	Moderate	3	**14**	Medium
Dicamba	Low	75	8	4.6	1	Moderate	3	**12**	Medium
Hepta-BDE	Low	13	2	41	4	Moderate	3	9	Low
MCPA	**Moderate**	**100**	10	13	3	Low	5	18	High
Total ammonia	**High**	100	10	5.2	2	High	1	13	High
NOx-N (as nitrate)	Moderate	25	3	99	5	Moderate	3	**11**	Low
NOx-N (stressor)	**Very high**	100	10	99	5	Moderate	3	18	High
Total phosphorus (stressor)	**Very high**	100	10	12	3	Moderate	3	16	High
FRP (stressor)	**Very high**	100	10	29	3	Moderate	3	16	High
EC (stressor)	**High**	100	10	4.8	1	Moderate	3	14	High
Ammonium (stressor)	**Very high**	100	10	5.2	2	Moderate	3	15	High

Table 16: Summary of data used to prioritise chemicals for human exposures to leachates. The information used to determine the priority group is shown in bold/underline

Chemical/parameter	HQ_{max}	% HQ > 1		Relative standard error		Reliability of criteria concentration		Sum of scores	Priority group
		value	score	value	score	value	score		
Antimony	**Moderate**	**100**	10	7.2	2	High	1	13	High
Arsenic	**Moderate**	**100**	10	13	3	High	1	14	High
Cadmium	**Moderate**	**100**	10	27	3	High	1	14	High
Chromium	Low	100	10	15	3	High	1	**14**	Medium
Copper	Low	20	2	22	3	High	1	**6**	Low
Lead	**Moderate**	**100**	10	13	3	High	1	14	High
Manganese	Moderate	80	8	15	3	High	1	**12**	Medium
Mercury	Low	40	4	16	3	High	1	**8**	Low
Molybdenum	Low	100	10	8.9	2	High	1	**13**	Medium
Nickel	**High**	100	10	22	3	High	1	14	High
Sulfate	Low	80	8	10	2	High	1	**11**	Low
2,4-D	Low	25	3	84	5	High	1	**9**	Low
MCPA	Low	75	8	13	3	High	1	**12**	Medium
Nitrate	Low	20	2	99	5	High	1	**8**	Low
Nitrite	Moderate	20	2	99	5	High	1	**8**	Low

Table 17: Summary of data used to prioritise chemicals for agricultural exposures to leachates via livestock drinking water. The information used to determine the priority group is shown in bold/underline

Chemical/parameter	HQ_{max}	% HQ > 1		Relative standard error		Reliability of criteria concentration		Sum of scores	Priority group
		value	score	value	score	value	score		
Aluminium	Low	20	2	13	3	Moderate	3	8	Low
Cadmium	Low	60	6	27	3	Moderate	3	12	Medium
Copper	**<u>Moderate</u>**	**<u>100</u>**	10	22	3	Moderate	3	16	High
Lead	Low	100	10	13	3	Moderate	3	16	Medium
Manganese	Low	40	4	15	3	Moderate	3	10	Low
Nickel	Low	20	2	22	3	Moderate	3	8	Low
Calcium	Low	20	2	13	3	Moderate	3	8	Low
Chloride	Low	40	4	3.7	1	Moderate	3	8	Low
Nitrite	Low	20	2	99	5	Moderate	3	10	Low
EC	Low	100	10	4.8	1	Moderate	3	14	Medium

Table 18: Summary of data used to prioritise chemicals for agricultural exposures to leachates via irrigation water. The information used to determine the priority group is shown in bold/underline

Chemical/parameter	HQ_{max}	% HQ > 1		Relative standard error		Reliability of criteria concentration		Sum of scores	Priority group
		value	score	value	score	value	score		
Aluminium	Low	60	6	13	3	High	1	**10**	Low
Arsenic	Low	20	2	13	3	High	1	**6**	Low
Boron	Low	100	10	13	3	High	1	**14**	Medium
Cadmium	Low	100	10	27	3	High	1	**14**	Medium
Chromium	Low	80	8	15	3	High	1	**12**	Medium
Cobalt	Low	80	8	15	3	High	1	**12**	Medium
Copper	**Moderate**	**100**	10	22	3	High	1	**14**	High
Iron	**High**	100	10	13	3	High	1	14	High
Manganese	**Moderate**	**100**	10	15	3	High	1	**14**	High
Molybdenum	**Moderate**	**100**	10	8.9	2	High	1	**13**	High
Nickel	**Moderate**	**100**	10	22	3	High	1	**14**	High
Zinc	Low	80	8	16	3	High	1	**12**	Medium
Sodium	Low	100	10	5.3	2	High	1	**13**	Medium
Chloride	Low	100	10	3.7	1	High	1	**12**	Medium
Dicamba	**Very high**	100	10	4.6	1	Moderate	3	14	High
Phosphorus	**Moderate**	**100**	10	12	3	High	1	**14**	High
EC	**Moderate**	**100**	10	4.8	1	High	1	**12**	High
Sodium adsorption ratio	Low	100	10	7.2	2	High	1	**13**	Medium

Part IV Additional assessment considering land application rates

Section Summary

The additional phase of assessment presented in this Part compares soil concentrations and soil porewater concentrations at different land application rates to criteria concentrations for the solid material and the leachates, respectively. The use of the soil porewater concentrations for the leachate exposures assumes that these concentrations are the maximum concentrations of each chemical that may move off site via leachate or surface runoff. The different land application rates considered were 140 and 10 t/ha as these represent the maximum allowable land application rates for mine site rehabilitation and broad acre agriculture, respectively. In all cases, the chemicals of concern were less at the lower application rate, however this information needs to be considered in relation to the application rates required to achieve agronomic benefit.

For the solid material, all of the chemicals that were identified as high priority following the tier 1 hazard assessment and data quality assessment (Part III) were further assessed in this Section. When the concentrations in the MWOO were adjusted for the different land application rates, aluminium was found to have the highest soil concentration with average predicted concentrations of 590 and 47 mg/kg following land application at 140 and 10 t/ha, respectively. The HQ_{max} values were greater than 1 for all of the chemicals, with the exception of EC, supporting their selection as high priority chemicals in the terrestrial environment for ecological and human receptors. In addition to this, aluminium, manganese, zinc, phenol, dibutyl phthalate, penta-BDE and total PBDEs could be considered very high priority due to the magnitude of the HQ_{max} values and/or the proportion of HQ values greater than 1.

To assess the leachates, only the metals (and total phosphorus) that were identified as high priority following the tier 1 assessment and data quality assessment (Part III) were considered. This was because the metals provided the most robust data set to calculate solid - solution partitioning coefficients (Kd). The Kd values for aluminium and lead indicated that these metals are likely to partition the least into the solution phase. In contrast, molybdenum, cobalt and nickel were predicted to partition the most. The soil porewater calculations indicated that the highest porewater concentrations following land application of MWOO were likely to be present for phosphorus and iron, where the average predicted concentration following land application at 140 t/ha was 320 and 290 µg/L respectively. Overall, the ecological receptors produced the highest HQ values indicating that aquatic ecology is more sensitive that the other receptors considered (humans and agriculture). For the ecological receptors, the outcomes from this additional phase of assessment supported the selection of high priority chemicals as they produced HQ_{max} values greater than 1 (with the exception of mercury and nickel). In addition, aluminium, chromium, copper, phosphorus and zinc could be considered very high priority based on the outcomes of this assessment. For the remaining receptors and exposures (human, stock drinking water and irrigation) most of the metals did not produce HQ_{max} values greater than 1, with the exception of lead for human health and iron for irrigation.

Although this is the case, all these chemicals should still be considered as high priority based on the tier 1 hazard assessment and data quality assessment as the possible environmental influences following land application of MWOO have not been considered (e.g. the possible effect of soil type on the mobility of the chemicals. This additional information should be considered in future work on these metals and the risks that they pose to the environment and human health.

13 Introduction

The tier 1 assessment presented in Part III, was a worst case scenario hazard assessment that assumed direct exposure of receptors to the MWOO solid material and the leachates that were generated during the experimental work. This is an unrealistic exposure scenario as it does not take into account dilution of the material or the leachates or any other mitigating factors in the environment, however it is consistent with a tier 1 assessment. In this section, the chemicals that were identified as high priority through the tier 1 hazard assessment will be considered further assuming different land application rates.

The permitted land application rates for this material in NSW are outlined in the RRE. In summary, the maximum allowable land application rates for different land uses are:

- 140 t/ha for mine site rehabilitation
- 50 t/ha for plantation forestry and for non-contact agriculture
- 10 t/ha for broad acre agriculture

For the assessment conducted in this section, application rates of 140 t/ha and 10 t/ha were considered as they represent the two extremes of the maximum allowable land application rates for the different land uses. To assess the solid material at these application rates, the concentrations in the MWOO were converted to concentrations in the soil. To further assess the leachates, the soil pore water concentrations were predicted based on solid solution partitioning coefficients for each of the chemicals. This approach to assess the leachates assumes that the soil pore water concentrations are the maximum concentrations of each chemical that may move off site as leachate or surface runoff.

This section can be used as another line of evidence to support the selection of high priority chemicals. It is acknowledged that in the field there will be some influence of soil type on the bioavailability and mobility of the chemicals in MWOO but this effect cannot be accounted for using the data generated as part of this project. For this reason, the outcomes of this phase of the assessment should not be used to remove chemicals from the overall list of high priority chemicals identified in Part III but instead to support their selection as high priority chemicals. For a detailed assessment on the effect of soil types on the bioavailability and mobility of many of these chemicals, the outcomes from this project should be considered along with the outcomes and results from other projects in this research program (e.g. Project 4).

14 Assessment of the solid material

14.1 Methodology used to assess the solid material at different application rates

To assess the solid material at different land application rates, the total concentrations in the MWOO were first converted to concentrations in the soil. This was done for all chemicals or parameters that were identified as high priority in the solid material following Part III. This included aluminium, copper, manganese, zinc, phenol, DEHA, DEHP, dibutyl phthalate, BPA, dibutyl tin, commercial penta-BDE, total PBDEs and electrical conductivity. All of these chemicals (or parameters), with the exception of total PBDEs, were considered high priority for terrestrial ecological receptors. Whereas, total PBDEs was considered high priority for human receptors exposed to the solid material.

To convert the concentrations of the chemicals (or parameters) in the MWOO to soil concentrations at different application rates, the MWOO concentrations were multiplied by a dilution factor (equation 1).

$$conc. in\ soil = \ conc. in\ MWOO \times \left[\frac{mass\ MWOO}{mass\ soil + mass\ MWOO}\right] \tag{1}$$

The mass of MWOO was either 10 or 140 t (based on application rates of 10 and 140 t/ha, respectively) and the mass of soil was assumed to be 1300 t. This calculated mass of soil assumes a soil bulk density of 1.3 g/cm^3 and an incorporation depth of the material to 10 cm, resulting in 1300 t/ha of soil into which the MWOO is incorporated (Langdon et al., 2010).

Following this, the concentrations of the chemicals in the soil converted to HQ values using the approach and criteria concentrations outlined in the previous sections. This approach assumes that there are no adverse effects cause by background concentrations of each of these chemicals and only considers the 'added' contaminant concentration.

14.2 Outcomes of additional assessment of the solid material at different application rates

Using equation 1, all of the measured concentrations of the high priority chemicals in the solid material were converted to soil concentrations and a summary of the converted concentrations is shown in Table 19. In calculating the summary statistics in Table 19, concentrations that were below the LOQ were included as the LOQ concentration.

Table 19: Summary of soil concentrations of high priority chemicals following land application at 140 t/ha and 10 t/ha

Chemical/parameter	Added soil concentrations at application rate of 140 t/ha (mg/kg)					Added soil concentrations at application rate of 10 t/ha (mg/kg)				
	Average	Minimum	Maximum	Median	95th percentile	Average	Minimum	Maximum	Median	95th percentile
Aluminium	590	400	2040	550	820	47	31	160	44	65
Copper	42	6.1	880	17	110	3.3	0.48	69	1.3	8.9
Manganese	28	18	130	24	40	2.2	1.4	9.9	1.9	3.1
Zinc	55	26	500	47	71	4.3	2.1	39	3.7	5.6
Phenol	2.5	<0.041	9.5	2.1	5.8	0.20	<0.0032	0.75	0.16	0.46
DEHA	1.6	<0.22	5.1	0.90	5.0	0.12	<0.018	0.40	0.071	0.39
DEHP	12	0.97	250	11	18	0.95	0.076	20	0.84	1.4
Dibutyl phthalate	0.50	0.10	1.8	0.34	1.1	0.039	0.0080	0.14	0.027	0.090
Bisphenol A	2.7	0.39	9.7	1.8	6.4	0.20	0.031	0.76	0.14	0.50
Dibutyl tin	0.0011	0.00021	0.0027	0.00080	0.0027	0.000092	0.000017	0.00021	0.000063	0.00021
Penta-BDE (commercial)	0.97	0.0027	11	0.010	5.2	0.076	0.00021	0.89	0.00080	0.41
Total PBDEs	6.1	0.0093	70	0.23	32	0.48	0.00073	5.5	0.018	2.5
Electrical conductivity (dS/m)	0.82	0.51	1.4	0.82	1.2	0.064	0.040	0.11	0.064	0.090

Hazard quotients were then calcuated for each of the estimated soil concentrations at 10 and 140 t/ha (Figure 20 and Figure 21) by comparing with the criteria concentrations used in the previous sections (Table 6). At a land application rate of 140 t/ha all chemicals had HQ values that were above 1 (Figure 20), with the exception of electrical conductivity that has all HQ values less than one. This indicates that the dilution of the material following application at 140 t/ha may be sufficient to reduce the risk posed by the salinity of the material. For the remaining chemicals, there was some distribution of HQ values above and below 1, with the exception of aluminium, manganese, zinc and dibutyl phthalate, which had all HQ values greater than 1.

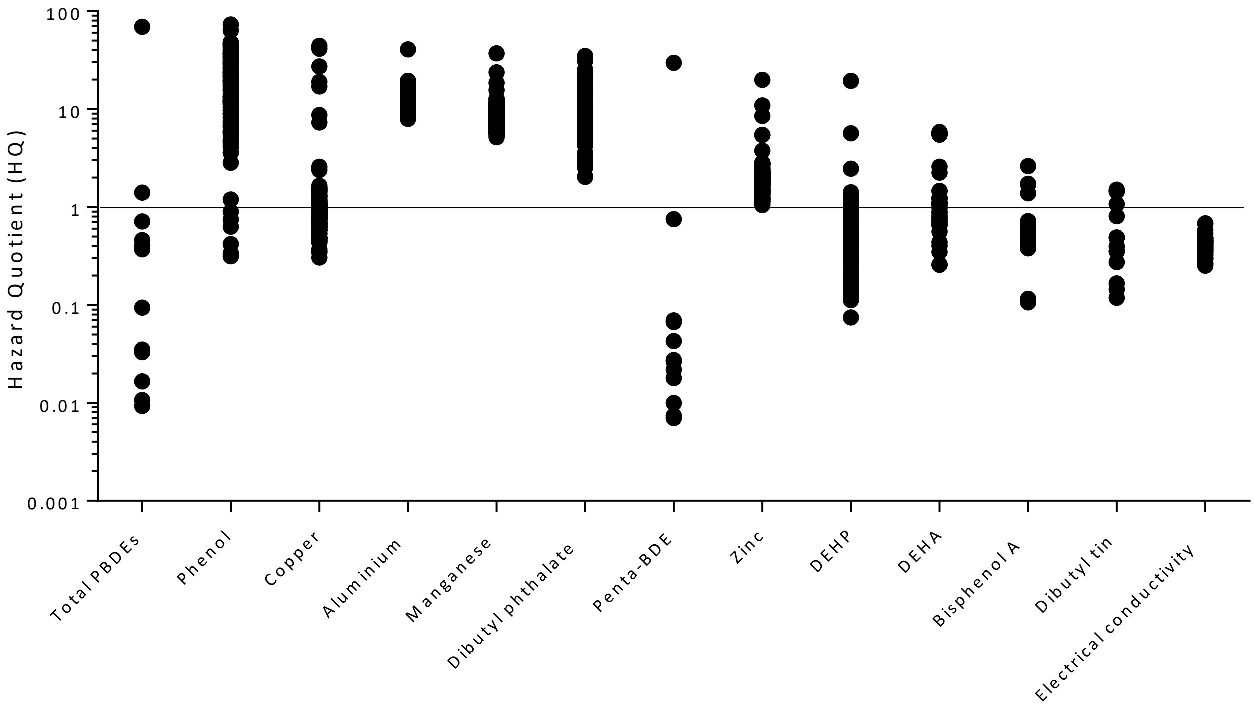


Figure 20: Hazard quotient distribution for soils following application of MWOO at 140 t/ha. All chemical concentrations are compared against terrestrial ecological criteria concentrations, except PBDEs, which are compared against human health criteria. The solid line indicates where HQ = 1.

The HQ values for the soil following MWOO application at 10 t/ha were all considerably lower than those presented for soil following application at 140 t/ha and were all below 10. In this case, in addition to the electrical conductivity, DEHA, BPA and dibutyl tin also had all HQ values less than 1. This indicates that for these chemicals (and parameters) following application at 10 t/ha the risks are likely to be negligible. The remaining chemicals had HQ values that were above and below 1, however in contrast to the application at 140 t/ha, none of the chemicals showed all HQ values to be above 1.

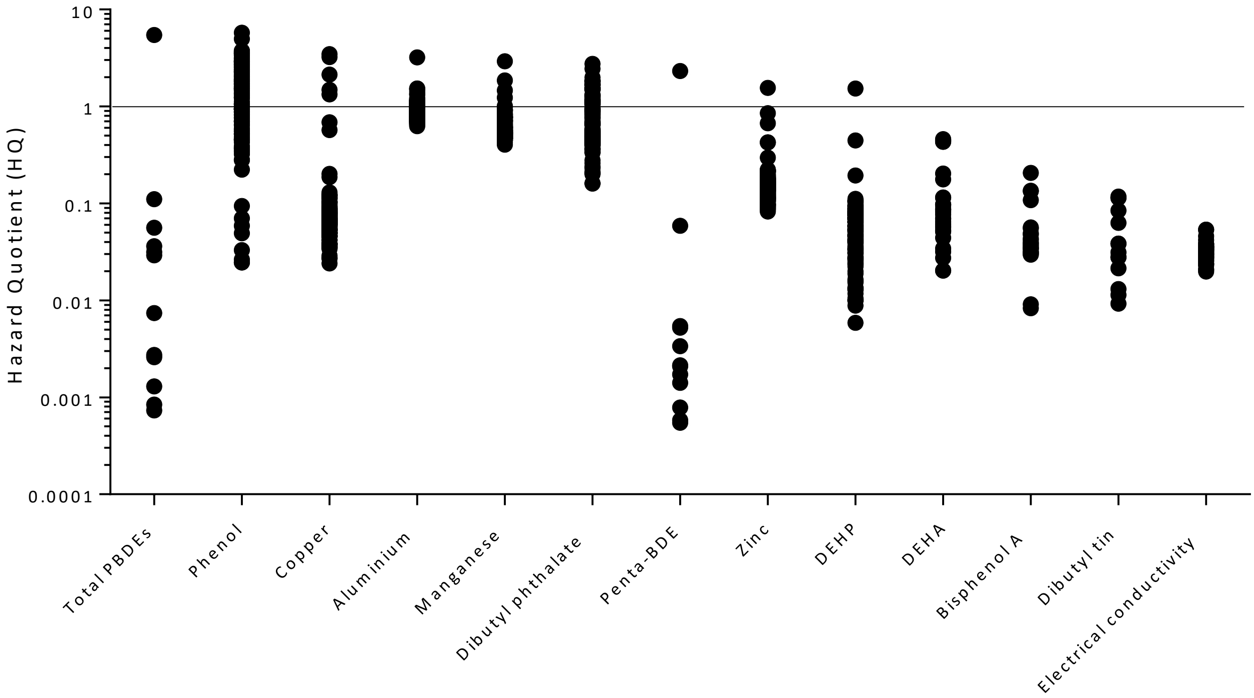


Figure 21: Hazard quotient distribution for soil following application of MWOO at 10 t/ha. All chemical concentrations are compared against terrestrial ecological criteria concentrations, expect PBDEs, which are compared against human health criteria. The solid line indicates where HQ = 1.

To assess the HQ data that were generated for the soils following land application of MWOO at 140 and 10 t/ha, the HQ_{max} values (from the 95th percentile of HQ values) and the proportion of concentrations that exceeded a HQ of 1 were determined (Table 20). As this is a more realistic exposure scenario (i.e. considers soil concentrations following MWOO application rather than just MWOO concentrations), any chemical with a HQ_{max} value greater than 1 is considered to be of concern. Therefore, at 140 t/ha all of the chemicals are considered to be of concern, with the exception of electrical conductivity. Of these chemicals, aluminium, manganese, zinc and dibutyl phthalate are of primary concern as all of the HQ values following application at 140 t/ha are greater than 1.

As expected, with an MWOO application rate of 10 t/ha, there is greater dilution of the material and all HQ_{max} values are considerably lower. For this land application scenario, only aluminium, phenol, dibutyl phthalate, commercial penta-BDE and total PBDEs produced HQ_{max} values greater than one, indicating that at this land application rate these are chemicals of concern. In contrast to the 140 t/ha land application scenario, none of the chemicals produced 100% of HQ values greater than 1 when a land application rate of 10 t/ha was assumed. Although the chemicals of concern are less at the lower application rate, this information needs to be considered in relation to application rates required to achieve agronomic benefits.

Table 20: Summary of HQ_{max} values (from 95th percentiles) and percentages of HQ values greater than 1 chemicals in soils following MWOO application at 140 and 10 t/ha. HQ_{max} values greater than 1 are shown in bold.

Chemical	140 t/ha		10 t/ha	
	HQ_{max}	% > HQ=1	HQ_{max}	% > HQ=1
Aluminium	**16**	100	**1.3**	31
Copper	**5.6**	38	0.44	3.9
Manganese	**12**	100	0.92	3.9
Zinc	**2.8**	100	0.22	0.78
Phenol	**45**	94	**3.5**	56
DEHA	**5.7**	52	0.45	0
DEHP	**1.4**	23	0.11	0.78
Dibutyl phthalate	**23**	100	**1.8**	27
Bisphenol A	**1.7**	17	0.14	0
Dibutyl tin	**1.5**	29	0.12	0
Penta-BDE (commercial)*	**30**	8.3	**2.3**	8.3
Total PBDEs*	**70**	17	**5.5**	8.3
Electrical conductivity (dS/m)	0.58	0	0.09	0

* HQ_{max} values are from the highest concentration due to the high variability in the concentration data

This information can be used to further support the selection of high priority chemicals following Part III of this report. As all of the chemicals listed in Table 20 have HQ_{max} values greater than 1 for the land application rate of 140 t/ha, with the exception of electrical conductivity, this indicates that all of these chemicals would still be considered high priority even after this more realistic exposure scenario is considered. Of these chemicals, aluminium, manganese, zinc, phenol, dibutyl phthalate, commercial penta-BDE and total PBDEs would be considered very high priority as 100% of the HQ values at 140 t/ha were greater than 1 and/or the HQ_{max} values were still greater than 1 at a land application rate of 10 t/ha.

15 Assessment of the leachates

15.1 Methodology used to assess the leachate at different application rates

To assess the leachates at the different application rates, soil porewater concentrations were predicted based on Kd values. The Kd values were calculated from the batch extraction data collected in the experimental phase of this project (Section 2.2.1). This approach allows soil porewater concentrations to be calculated for all measured concentrations in the solid material, rather than just for the small number of samples that were leached.

This additional assessment of the leachates was only done for the metals (and total phosphorus as a stressor) that were identified as high priority in Part III. This was because although a number of organic compounds were also identified as being high priority, the data for these compounds was considerably more variable with many leachate concentrations (from the batch extractions) being close to or below the LOQs. This resulted in unreliable Kd values and therefore unreliable soil pore water concentrations.

Kd values give an indication of the partitioning between the solid and solution phases in soil (or in this instance MWOO). The calculation takes into account the total concentration of an analyte in the solid phase, the solution concentration following an extraction with water and the mass of solid and volume of water used for the extraction. The calculation of Kd values is shown in Equation 1 (adapted from Sepulvado et al., 2011).

$$K_d = \frac{C_s}{C_w} = \frac{m_s^0 - m_w}{m_w} \times \frac{V_w}{M_{soil}} \qquad (1)$$

Where, C_s is the concentration of the chemical in the solid phase, C_w is the concentration of the chemical in the aqueous phase, m_s^0 is the mass of the chemical in the solid phase before desorption, m_w is the mass of chemical in the aqueous phase after desorption, V_w is the volume of the aqueous phase used in the extraction and M_{soil} is the mass of soil used in the extraction. The use of this equation assumes that there is no loss of any of the chemicals onto the extraction vessel and that the distribution of chemicals between the solid and solution phases is at equilibrium. The Kd provides an indication of the partitioning between the solid and solution phases and the lower values indicate greater chemical in solution and a Kd of 1 indicates that the partitioning is equal between the solid and solution phases (i.e. 1 to 1 distribution).

To calculate the Kd values in this project the average solid concentration and the average leachate concentration from the batch extractions was used. This was done for each facility and each season, which provided a range of Kd values for each of the chemicals.

Following this, the average Kd values were then used to calculate the soil porewater concentrations. This was done for the full range of soil concentrations calculated in Section 14.2 at land application rates of 140 and 10 t/ha. The approach used was based on Langdon et al. (2010) and Chari & Halden (2012), which assume that the soil porewater concentration calculated from the total soil concentration and the Kd value represents the maximum leachate or run-off water concentration at each soil concentration. This was done using two equations. The first equation was obtained be rearranging the equation used to experimentally determine Kd (OECD, 2000) and calculated the ratio of the mass bound to the mass in solution (at equilibrium). This was done per given volume of soil (i.e. 1.3 cm^3) and is shown in equation 2

$$m_s/m_w = \frac{(K_d.M_{soil})}{V_w} \tag{2}$$

Where m_s is the mass of the chemical bound to the solid phase at equilibrium (µg) (i.e. starting total mass minus the mass in solution at equilibrium), m_w is the mass of the chemical in the aqueous phase at equilibrium (µg), *Kd* is the solid solution partitioning coefficient (average from Table 21), M_{soil} is the mass of soil in 1 cm^3 (g dry weight) (i.e. 1.3 g as stated in Section 14.1) and V_w is the volume of aqueous phase in 1 cm^3 soil (mL) (i.e. 0.5 mL). The use of 0.5 mL for V_w assumes that the soil has a porosity of 50% and that the soil is saturated.

The mass of each chemical in the aqueous phase in the same volume (i.e. 0.5 mL) was then calculated by using equation 3

$$m_w = \frac{m_s^0}{\left(m_s/m_w\right)+1} \tag{3}$$

Where m_s^0 is equal to the total mass (µg) of the chemical in 1 cm^3 soil (i.e. 1.3 g) before desorption, which is calculated from soil concentrations (see Section 14.1). The ratio $\left(m_s/m_w\right)$ is calculated from equation (2) above. Therefore m_w, as calculated from equation 3, relates to the mass of the chemical in 0.5 mL water (i.e. 1 cm^3 of soil at saturation). This value was then converted to a concentration for comparison against the criteria concentrations.

This series of calculations was undertaken for all measured chemical concentrations in the solid material, therefore a range of possible soil pore water concentrations was determined. This approach assumes that the estimated porewater concentrations represent the exposure concentration and that no dilution has occurred. In this instance, it also assumed that the soil to which the MWOO is applied does not have any influence on the partitioning of the chemicals from the MWOO. It is still a conservative assessment, however it is more realistic than the assessment shown in Part III.

15.2 Outcomes of additional assessment of leachates at different application rates

In order to complete the Kd calculations, data must be available for both the solid material and the batch extractions. In some cases (arsenic, cadmium and tin), either all or most of the batch extraction data were below the LOQ, therefore a Kd could not be calculated. The Kd values for the remaining metals are listed in (Table 21). The Kd values indicate that aluminium, iron and lead showed the lowest degree of partitioning into the solution phase (i.e. these metals had the highest Kd values). In contrast, molybdenum, cobalt and nickel showed the greatest degree of partitioning into the solution phase.

Table 21: Summary of average, minimum and maximum solid solution partitioning coefficients (Kd) for each chemical identified as high priority for each exposure pathway

Chemical	Exposure pathway	Kd values		
		Average	Minimum	Maximum
Aluminium	Ecological	2750	2010	4330
Antimony	Human	553	178	1050
Barium	Ecological	2230	1680	3100
Chromium	Ecological	1030	339	2620
Cobalt	Ecological	205	98.6	434
Copper	Ecological, livestock, irrigation	1050	343	3430
Iron	Ecological, irrigation	3340	2700	4130
Lead	Ecological, human	2430	1900	4300
Manganese	Irrigation	639	129	2060
Mercury	Ecological	1870	834	3890
Molybdenum	Irrigation	178	51.1	524
Nickel	Ecological, human, irrigation	369	103	1230
Phosphorus	Ecological	1230	777	1948
Zinc	Ecological	523	175	1220

The range of soil porewater concentrations calculated from the Kd values for each of the metals at MWOO land application rates of 140 and 10 t/ha are summarised in Table 22. Using the median soil porewater concentrations, the highest estimated concentrations are for iron and phosphorus and the lowest are for mercury.

The HQ values for the soil pore water concentrations were calculated for each application rate (140 and 10 t/ha) (Figure 22 and Figure 23). Overall, the HQs for the ecological receptors were the highest and for the agricultural receptors they were the lowest. At 140 t/ha aluminium, chromium, copper and zinc for the ecological receptors had all HQ values greater than 1 (Figure 22). As expected, the HQ values at a land application rate of 10 t/ha were all considerably lower (Figure 23) and none of the chemicals showed all HQ values greater than 1. In fact, for a number of chemicals, the HQ values for the pore water following application at 10 t/ha were all less than one. This was the case for barium, iron and mercury for the ecological receptors, antimony for human receptors and all chemicals for agricultural receptors (livestock drinking water and irrigation).

Table 22: Summary of soil pore water concentrations of high priority chemicals following land application at 140 t/ha and 10 t/ha

Metal	Soil pore water concentration at application rate of 140 t/ha (µg/L)					Soil pore water concentration at application rate of 10 t/ha (µg/L)				
	Average	Minimum	Maximum	Median	95th percentile	Average	Minimum	Maximum	Median	95th percentile
Aluminium	220	150	740	200	300	17	11	58	16	23
Antimony	1.1	0.54	28	0.56	2.1	0.085	0.043	2.2	0.044	0.17
Barium	5.7	3.7	27	5.2	8.7	0.45	0.29	2.1	0.41	0.68
Chromium	4.1	1.6	42	3.7	6.0	0.32	0.13	3.3	0.29	0.47
Cobalt	2.3	1.4	24	2.1	2.9	0.18	0.11	1.9	0.16	0.22
Copper	40	5.8	840	16	110	3.2	0.46	66	1.2	8.4
Iron	290	150	760	260	500	23	11	59	21	39
Lead	8.4	1.7	52	7.6	14	0.66	0.13	4.1	0.60	1.1
Manganese	44	27	200	38	62	3.4	2.1	16	3.0	4.9
Mercury (ng/L)	14	0.730	68	13	32	1.1	0.057	5.3	0.98	2.5
Molybdenum	3.1	1.1	65	1.8	3.5	0.24	0.085	5.1	0.140	0.28
Nickel	18	3.2	760	6.4	11	1.4	0.25	60	0.51	0.88
Phosphorus	320	0.95	590	320	440	25	0.074	47	25	35
Zinc	110	50	950	89	130	8.2	3.9	74	7.0	11

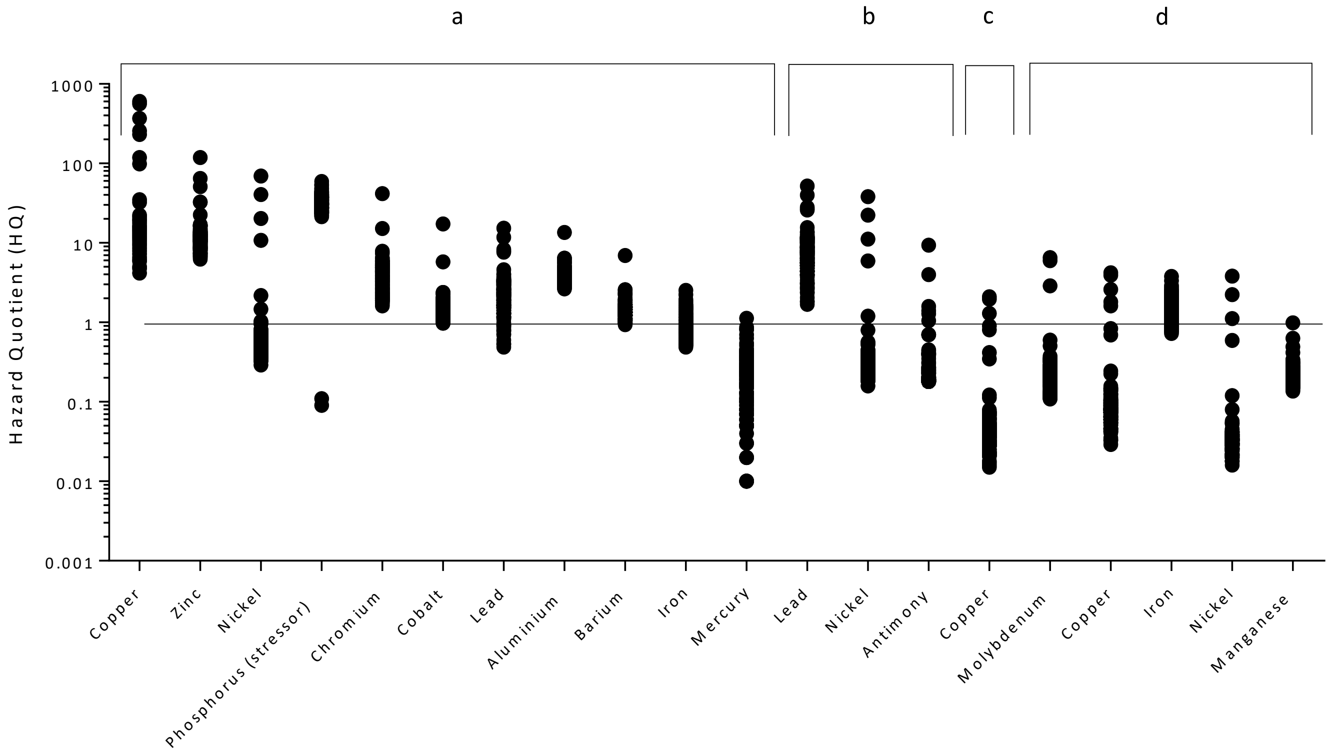


Figure 22: Hazard quotient distribution for soil pore waters following application of MWOO at 140 t/ha. The chemicals are compared to (a) ecological criteria, (b) human health, (c) stock drinking water and (d) irrigation criteria concentrations. The solid line indicates where HQ = 1.

A summary of the HQ_{max} values and the proportion of HQ values greater than 1 are shown in Table 23 for each exposure pathway assuming application rates of 140 and 10 t/ha. Overall, the ecological pathway produced the highest HQ values, indicating that ecological receptors are likely to be the most sensitive to chemicals in land applied MWOO. These values can be used to further support the selection of high priority chemicals. To do this, the same approach as outlined in Section 14.2 was used, whereby chemicals with HQ_{max} values greater than 1 at 140 t/ha were still considered to be high priority. In addition, chemicals that had 100% of HQ values greater than 1 at 140 t/ha and/or had HQ_{max} values greater 1 at 10 t/ha were considered to be very high priority. The more stringent criteria to assess these data are due to the more realistic exposure concentrations (i.e. this phase of the assessment is not as conservative as that presented in Parts II and III of this report).

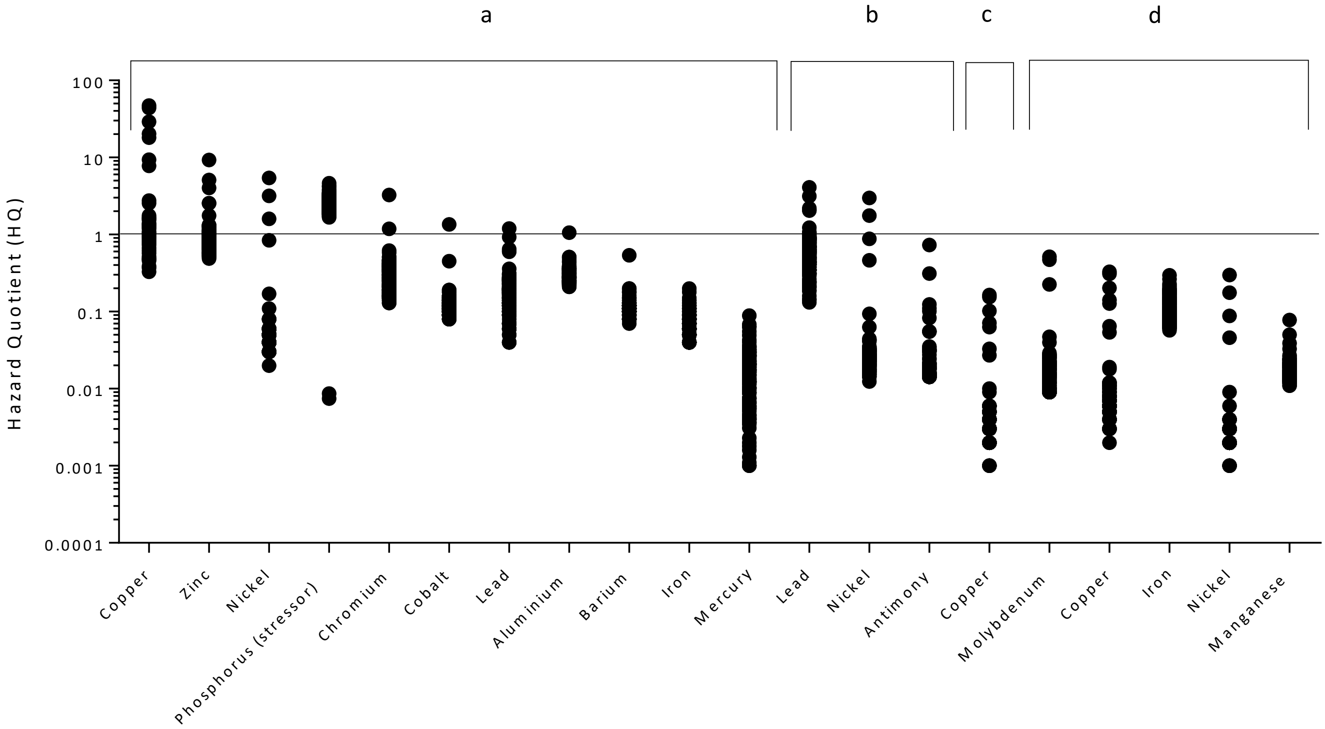


Figure 23: Hazard quotient distribution for soil pore waters following application of MWOO at 10 t/ha. The chemicals are compared to (a) ecological criteria, (b) human health, (c) stock drinking water and (d) irrigation criteria concentrations. The solid line indicates where HQ = 1.

Based on this additional assessment for the ecological exposures, all metals identified as high priority following the tier 1 assessment (Part III), are still likely to be a concern following land application at 140 t/ha, with the exception of mercury and nickel. This therefore supports them being identified as high priority chemicals. The HQ_{max} values for mercury and nickel at 140 t/ha were 0.59 and 1.0 respectively, indicating that based on the Kd values generated, the pore water concentrations of these metals are unlikely to reach a concentration that will pose a risk to aquatic organisms. Of the remaining chemicals, aluminium, chromium, copper, phosphorus and zinc would all be considered very high priority due to the magnitude of the HQ_{max} values and the proportion of HQ values greater than 1. These metals are therefore identified as the primary concern for aquatic organisms.

For human receptors exposed to the soil pore water concentrations, antimony and nickel produced HQ_{max} values that were less than 1. This indicates that for this exposure pathway, these metals are unlikely to be present at concentrations that pose a risk to human health. In contrast, lead produced a HQ_{max} value that were greater than 1 for both land application scenarios (140 and 10 t/ha), suggesting that this metal is of very high priority when considering human exposures to leachate or run-off from areas where MWOO has been applied.

Copper was the only metal identified as being high priority for the stock drinking water exposure pathway. The HQ_{max} values for copper in the additional assessment were all below 1, indicating that copper is unlikely to be present in the leachate or runoff at concentrations that pose a risk to livestock.

For the agricultural exposure pathway through irrigation water, copper, iron, manganese, molybdenum and nickel were all identified as being high priority following the tier 1 hazard assessment (Part III). Of these metals, only iron produced an HQ_{max} value greater than 1 following a land application rate of 140 t/ha. The HQ_{max} value for this metal was lower than 1 when a land application rate of 10 t/ha was assumed. For this reason, iron is likely to be the greatest concern of the high priority chemicals for the irrigation water exposures. For the remaining metals (copper, manganese, molybdenum and nickel), the HQ_{max} values were all less than 1, which suggests that it is possible that the dilution of these metals when land applying the material will mitigate the risks that they pose to agricultural receptors.

Table 23: Summary of HQ_{max} values (from 95th percentiles) and percentages of HQ values greater than 1 for soil pore water concentrations following MWOO application at 140 and 10 t/ha. HQ_{max} values greater than 1 are shown in bold.

Pathway/receptor	Chemical	140 t/ha		10 t/ha	
		HQ_{max}	% > HQ=1	HQ_{max}	% > HQ=1
Ecological	Aluminium	**5.4**	100	0.43	0.78
	Barium	**2.3**	96	0.18	0
	Chromium	**6.0**	100	0.47	1.6
	Cobalt	**2.1**	98	0.16	0.78
	Copper	**77**	100	**6.00**	34
	Iron	**1.6**	40	0.13	0
	Lead	**9.0**	88	0.31	0.78
	Mercury	0.54	0.78	0.042	0
	Nickel	1.0	6.3	0.080	2.3
	Phosphorus	**44**	98	**3.5**	98
	Zinc	**17**	100	**1.3**	27.3
Human	Antimony	0.70	4.7	0.055	0
	Lead	**14**	88	**1.1**	7.0
	Nickel	0.56	3.9	0.044	1.6
Livestock	Copper	0.27	2.3	0.021	0
Irrigation	Copper	0.54	3.90	0.042	0
	Iron	**2.5**	83	0.19	0
	Manganese	0.31	0	0.024	0
	Molybdenum	0.35	2.3	0.028	0
	Nickel	0.056	2.3	0.0044	0

This additional assessment shows that overall aquatic ecological receptors are likely to be the most sensitive to metals in MWOO that may move off site via leachate or runoff water. Although this additional assessment suggested that the risk of some of these metals may be mitigated at the two land application rates considered, this outcome should not be used to remove these chemicals from this list of high priority chemicals without additional consideration of other effects that might take place in the environment. For example, if the MWOO is applied to a soil with a lower pH than the material, there may be an increase in the mobility of some of these metals. Therefore, the results from this section should be considered in conjunction with results from other projects in this research program.

Part V Discussion of potential risk mitigating factors in the environment

Section Summary

The previous sections of this report focussed on categorising the chemicals that were detected in the MWOO solids and leachates into priority groups based on the data that was collected during the study. In Parts II and III of this report, the concentrations measured in the samples were considered to be the direct exposure concentrations. This approach is consistent with a tier 1 assessment, however it is a highly conservative approach as there are many mitigating factors that may alter the exposure concentrations of a chemical following land application of MWOO. In addition, in Part IV of this report, the mitigating factor of dilution of the material at different land application rates was considered. It is beyond the scope of this project to consider all possible mitigating factors in a detailed risk assessment, however these factors should be considered in future risk assessment work focussing on the high priority chemicals.

The following sections discuss some of the key factors that may mitigate or change the potential risks of chemicals in MWOO following land application, including: the persistence of chemicals in soil following land application of MWOO; the effects of bioavailability and speciation; and physical and geological factors affecting leachate transport. These mitigating factors will be discussed separately but in the environment many of the factors are linked. For example, the degradation of organic compounds in the soil is often influenced by their bioavailability to biodegrading microorganisms. This Part will provide a general overview of these factors with a focus on the chemicals categorised as being high priority following Part III. This discussion can assist in the interpretation of results and help guide future research.

Three aspects affecting chemical persistence in soil are discussed, including degradation (organic and organo-metallic compounds only), chemical transformations and losses through leaching. The degradation of a compound in soil can be highly dependent on soil type and climatic conditions. Of the high priority compounds, phenol is likely to be rapidly degraded, which under field conditions would reduce its overall risk. The other compounds categorised as high priority have been shown to persist to some extent, especially following land application of waste. Studies investigating the degradation of the high priority compounds following land application of MWOO would be warranted.

The chemical transformations discussed include transformations of ammonia to nitrate and oxidation of sulfide. In soils, the potential risks posed by these chemicals may be reduced by these chemical transformations. However, as these transformations are biologically driven, an understanding of the effect of MWOO on soil microbial function is required. This is particularly important for ammonia and sulfide as these were identified as being two of the primary aquatic toxicants in the MWOO leachates from the TIE (Part I).

The possible loss of chemicals from the soil surface through leaching following land application of MWOO may reduce the risk posed by a chemical at the soil surface. This was considered in more detail for the metals aluminium, copper, manganese and zinc using the column leachate data. Of these metals, manganese released the greatest proportion through leaching (35% of the total concentration), whereas, aluminium released the least (2.5% of the total concentration). This suggests a greater ongoing concern for aluminium compared to manganese at the soil surface.

The bioavailability of the chemicals in the soil and leachates was considered. Soil type plays an important role in the bioavailability and toxicity of chemicals. This means that some soils have a greater ability to bind chemicals making them less bioavailable compared to other soils. These differences should be considered when determining suitable land application rates for MWOO.

In the leachates, metal speciation was investigated using the computer modelling package Visual MINTEQ. This showed that for most of the high priority metals, the majority (95-100%) of the measured metal concentrations in the leachates is likely to be bound to natural organic matter in solution. This will reduce their bioavailability and overall risk and should be considered when interpreting the results from this study. The metals that showed the greatest proportion of dissolved inorganic species included barium (28%) and cobalt (3.5%). These metals may require further consideration of their ecotoxicity.

Finally, the possible physical and geological factors that may affect leachate transport and dilution are discussed. The transport through the soil profile is mainly affected by the soil hydraulic conductivity. This factor is strongly influenced by soil texture and structure, for example, leachates will move through a sandy soil quicker than through a clay soil. In addition, a range of aquifer factors will also influence the extent of dilution that is likely to occur when leachates reach groundwater. This will change the concentration that is likely to reach an off-site receptor (e.g. surface water or groundwater bore). These are all site-specific factors and include hydraulic gradient, mixing zone, infiltration rate and hydraulic conductivity.

16 Persistence of chemicals in the soil following land application of mixed waste organic outputs

One of the primary mitigating factors to be considered when assessing the potential ongoing risks associated with chemicals following land application of MWOO is their persistence. As most of the guideline values that have been developed for chemicals are based on long-term chronic exposures, persistence is an important consideration. There are many processes by which chemicals can be removed from a system, however, the main processes that will be discussed in this section are degradation (organic and organo-metallic compounds only), environmental transformations of inorganic chemicals (e.g. oxidation or volatilisation of ammonia) and leaching.

16.1 Degradation of organic and organo-metallic compounds

Processes of degradation are important in understanding the potential long-term risks associated with organic and organo-metallic compounds following land application of MWOO. The detailed hazard assessment presented in Part III identified a range of organic and organo-metallic compounds that were considered high priority as a result of both on-site effects and potential offsite effects through exposure to leachates. These compounds included phenol, a range of plasticisers (DEHA, DEHP and DBP), PBDEs, some pesticides (MCPA and dicamba) and the plastic constituent BPA. Several of these (phenol, dibutyl phthalate, penta-BDE and total PBDEs) were also identified as very high priority following the additional assessment presented in Part IV. If these compounds are expected to degrade in the environment following land application of MWOO, this may reduce their overall risk. When considering degradation however, it is also important to consider the degradation products that are produced. In some cases these can be more persistent and/or toxic than the parent compounds. For example, photolytic debromination of deca-BDE produces lower brominated PBDE congeners that are more toxic than the parent compound (see below).

It can be difficult to gain an understanding of degradation rates of organic compounds in soils following land application of wastes, as the degradation rates tend to be site-specific and can be highly variable. Studies investigating the degradation of organic compounds following land application of biosolids (e.g. BPA, 4NP and the antimicrobial agent triclosan) have indicated that degradation in the field is slower than that observed in the laboratory (Langdon et al., 2012). In addition, there is some evidence to suggest that the degradation from waste applied to land (biosolids in this case) can result in a persistent fraction of the compounds that remains in the soil and is resistant to degradation (Langdon et al., 2011, Langdon et al., 2012, Davis et al., 2015). To better understand the potential for degradation of organic compounds in soil following land application of MWOO, further experimental work aimed at addressing this would be required. The section below summarises some of the information that is currently known about the soil degradation of the organic and organo-metallic compounds identified as high priority following Part III.

16.1.1 Degradation of phenol

Microbial biodegradation is the dominant pathway for degradation of phenol in the environment. It is generally considered to be rapid (e.g. ECHA reports that the aerobic biodegradation half-life (DT50) in soil is 7 days), however, degradation may be hindered or precluded by the presence of toxically high concentrations of phenol or other chemicals, or by factors such as a lack of nutrients or microorganisms capable of degrading phenol (ATSDR, 2008). Degradation under anaerobic conditions can be much slower than under aerobic conditions. For example, Shibata et al. (2006) reported that phenol in soil under aerobic conditions degraded within several days, whereas, under anaerobic conditions, the DT50 for phenol in soil was 24 to 260 days. This information suggests that if phenol is added to soils through land application of MWOO, it is likely that in an aerobic agricultural soil this compound will readily degrade, therefore, reducing the longer term risk it may pose.

16.1.2 Plasticisers – DEHA, DEHP and dibutyl phthalate

Microorganisms play an important role in the degradation of these plasticisers in the environment. Studies have demonstrated that phthalates with shorter ester chains (e.g. dibutyl phthalate) can be readily biodegraded, whereas phthalates with longer ester chains (e.g DEHP) are less susceptible to biodegradation (Wang et al., 2000, Chang et al., 2004). The degradation of phthalates is a process that takes place in aerobic conditions, and these compounds are not readily degraded under anaerobic conditions (He et al., 2015). Comparatively more work has been conducted on the environmental fate and degradation of DEHP than dibutyl phthalate. The results from studies investigating the degradation of DEHP in soils are highly variable and rates are mostly dependent on temperature and soil type. For example, the European Union Risk Assessment Report (EU, 2008) states that degradation rates for DEHP in soil range from 92% degradation after 30 days to only 3% mineralisation after 100 days. Studies investigating the degradation of DEHP in soil following application of wastes have also indicated that this compound shows moderate persistence. For example, Tran et al. (2015) reported the DT50 of DEHP in soils following application of sludge was 64 days in the top 0-20 cm.

In comparison to the phthalate compounds, fewer studies have been conducted on degradation of DEHA due to the more recent use of this compound. Microbial biodegradation is likely to be an important mechanism and ECHA reports that under aerobic conditions it is readily degraded in water. No information relating to the degradation of this compound in soil could be found.

Due to these compound being identified as high priority in Part III, it is recommended that a more detailed evaluation of their likely persistence in soil following land application of MWOO be undertaken.

16.1.3 Polybrominated diphenyl ethers (PBDEs)

The PBDE compounds were highlighted through Part III as being a high priority for human health and the environment at the site of application (i.e. exposure to the solid material). The additional assessment presented in Part IV also suggested that these compounds may be very high priority. The dominant pathway for degradation of PBDE compounds is through photolysis. The majority of work has been conducted using deca-BDE (BDE-209), which shows that reductive debromination is the main photodegradation mechanism for this compound (Soderstrom et al., 2004, Bezares-Cruz et al., 2004). This results in lower brominated PBDE congeners that are actually more persistent, bioaccumulative and toxic than the parent compound (Fang et al., 2008). In the environment these compounds are considered to be highly persistent. In a study investigating the persistence of a range of chemicals, including BDE-47 (tetra-BDE) and BDE-209 (deca-BDE) following land application of biosolids, Davis et al. (2015) found that the concentrations of both compounds reached a steady state. This study was conducted over 90 days with degradation only taking place over the first 30 days. After this, the concentrations of both compounds reached a steady state of approximately 50% of the starting day 0 concentration in the soil. Although this study was done with biosolids, it suggests that PBDE compounds may have the potential to persist in soils for an extended period of time following land application of MWOO. This is of particular concern due to the potential for bioaccumulation and biomagnification of these compounds. All of the PBDE compounds, other than deca-BDE are listed on the Stockholm Convention, which is reserved only for the very highest priority persistent compounds. This highlights that there is global concern relating to use of these compounds and their release into the environment. The long-term persistence of PBDEs in soils will also have an influence on the risks associated with re-application. Further work should be conducted investigating how persistent PBDEs are in soils following land application of MWOO.

16.1.4 Pesticides – MCPA and dicamba

These two pesticides were identified as being of high priority following Part III. MCPA was identified for aquatic ecological receptors and dicamba for agricultural receptors exposed to leachates via irrigation water.

Microbial degradation is the most important degradation process for MCPA and dicamba in soil but photodegradation also contributes. Both compounds show low to moderate persistence in soil with DT50 values ranging from approximately 15 to 50 days for MCPA (Health Canada, 2010) and 17 to 60 days for dicamba (Altom and Stritzke, 1973, Krueger et al., 1991). The rate of degradation in soil depends on several factors, such as soil type, pH, moisture, climatic conditions and organic matter content (Health Canada, 2010).

16.1.5 Bisphenol A

The dominant pathway for degradation of BPA in soil is through microbial degradation. It is generally considered to degrade rapidly in the environment with DT50 values of approximately 4.5 days in soil (Cousins et al., 2002). There is some evidence, however, to suggest that degradation of BPA following land application of waste (in this case biosolids) results in incomplete degradation. A study conducted under laboratory conditions found that 32 weeks after biosolids addition to soil, 24-42% of the initial BPA concentration was still present (Langdon et al., 2011). A subsequent study also indicated the degradation rates in the field were approximately 2.5-times slower than those observed under laboratory conditions (Langdon et al., 2012). This information suggests that the degradation of BPA following land application of MWOO might be slower than reported in Cousins et al. (2002). Due to the high concentrations of BPA in the MWOO samples (up to 100 mg/kg) further evaluation of the expected persistence in the soil would be warranted.

16.1.6 Dibutyl tin

Dibutyl tin was identified as being high priority for the ecological exposures in the terrestrial environment following Part III. The degradation of DBT (and other organotins, mono- and tri-butyl tin) is through the sequential removal of the alkyl groups attached to the tin. Hence, tributyltin degrades to DBT and then MBT. The end product of organotin degradation is inorganic tin (Heroult et al., 2008, Dubascoux et al., 2008). Biotic processes are considered to be the most significant pathway for degradation of organotin compounds in terrestrial and aquatic environments (Marcic et al., 2006). The degradation of organotin compounds in soils can, however, be quite slow, with DT50 values for DBT ranging from 0.8 to 15 years in one study (Huang and Matzner, 2004). Based on this, further studies investigating the persistence of DBT following land application of MWOO would be warranted.

16.2 Environmental transformation of inorganic chemicals

16.2.1 Ammonia and nitrate

Total ammonia, ammonium and nitrate were all identified as being high priority for aquatic ecological receptors following the detailed hazard assessment (Part III). For total ammonia (NH_3 + NH_4^+) this was in terms of its potential to be toxic to organisms and it was also one of the primary toxicants identified through the TIE process (Part I). In contrast, for ammonium and nitrate this was due to their potential to act as stressors and ultimately affect ecosystem health.

In soils, ammonia and nitrate will be subject to a range of chemical transformation that will alter their concentrations in both the solid matrix and leachates following land application of MWOO. This may also alter the potential risks posed. One of these primary processes is nitrification, which will be discussed below, however, other processes including denitrification and volatilisation (e.g. of ammonia) may also be important. Nitrification is the biological oxidation of ammonium (NH_4^+) or ammonia (NH_3) to nitrate (NO_3^-). In soils it is a two-step process, in which ammonium or ammonia is first converted to nitrite (NO_2^-) and then to nitrate (NO_3^-). Nitrate is the predominant form of nitrogen assimilated by plants to assist with growth and development. The process requires oxygen and it is represented by the following equation:

$$NH_4^+ + 2O_2 \rightarrow NO_3^- + H_2O + 2H^+$$

Nitrification in soils is influenced by a number of parameters, including, presence of nitrifying organisms, pH, temperature, oxygen, moisture and substrate concentration and availability. As this is a biologically driven process there is a need to better understand the effect of MWOO on soil nitrification and overall soil functionality. If ammonia-N in soils is readily transformed to nitrate and then assimilated by plants, it decreases the overall risks associated with potential leaching of these mobile mineral forms of nitrogen in soil. To better understand the potential risks associated with ammonia and nitrate in soils, a better understanding of how MWOO may affect this biological process is required.

The release of mineral-N from organic-N in MWOO will also be an ongoing chemical transformation in soils following land application of MWOO. This is also a microbially driven process and has the potential to release more N into the system that may be readily leached. An additional consideration is that oxidation of excess reduced N can result in soil acidification (see equation above). Considering these factors, further investigation of the effect of MWOO on soil processes like mineralisation and nitrification would be warranted. This is particularly the case due to these nutrients being identified as high priority in the leachates. The risks posed to ecosystems through leaching of mineral forms on N from soil following land application of MWOO can be mitigated by considering the nitrogen concentration in the material and the crop requirements prior to application. If MWOO is added to soils at rates ensuring that the levels of N do not exceed the crop requirements then the potential for leaching of excess nitrogen from the soil will be reduced. The application of N fertilisers is done based on the N requirements of the crop. A similar approach is used in biosolids guidelines around the country where the nitrogen requirements of the crop are to be considered and application rates cannot exceed the nitrogen crop requirements. These calculations are conducted considering all forms of N (organic-N and mineral-N) and assume a standard mineralisation rate. This approach could be considered for land application of MWOO, however, further research would be required to better understand the mineralisation rate of MWOO following land application and the effect of MWOO on soil nitrification.

16.2.2 Sulfide

The presence of sulfide in the MWOO leachates was identified through the detailed hazard assessment (Part III) to be high priority to aquatic organisms. This is consistent with the results from the experimental work undertaken for this project, which identified sulfide as one of the primary aquatic toxicants through the TIE process (Part I).

Hydrogen sulfide is an anaerobic degradation product of chemicals containing sulfur and is commonly found in industrial wastes and landfill leachates. It exists as a gas at atmospheric pressure, therefore partitioning to air is likely to occur after environmental releases. It is also soluble in water and therefore may partition to surface waters, groundwater or moist soils and has the potential to travel through these media (WHO, 2003). In aqueous solution, hydrogen sulfide forms an equilibrium between un-ionised H_2S, bisulfide ions HS^- and sulfide ions S^2-. It is the un-ionised H_2S that is the more toxic form of sulfide and the amount of this present in relation to other species is pH, temperature and salinity dependant (ANZECC and ARMCANZ, 2000).

The presence of hydrogen sulfide in aerated soils is generally of low concern, as when it enters an oxygenated zone, it is rapidly oxidised by microorganisms. The negative effects of sulfide in soils are mainly related to water-logged anaerobic soils (e.g. rice paddy soils). Several species of soil, aquatic and marine microorganisms oxidise hydrogen sulfide to elemental sulfur and sulfate. The half-life of sulfide in these environmental systems, as long as there is oxygen present, is normally in the range of 1 hour to several hours (WHO, 2003). Based on this, it is likely that in a natural soil, even if some sulfide is released from MWOO following land application, it will be readily oxidised. Therefore, the potential for sulfide to be leached from MWOO and pose a risk to waterways may be reduced through this process. However, as the oxidation of sulfide is a microbially driven process, further work may be warranted to ensure that soil microbial communities are not negatively affected by MWOO application and are sufficiently functioning to complete this process. The risk posed by sulfide reaching groundwater may be increased if there is immediate rainfall following land application of MWOO and sulfide is transported to the lower soil profile or underlying aquifers which may be oxygen limited.

16.3 Losses of chemicals from the soil surface through leaching

The leaching profiles from the column leachate experiments shown in Part I indicated that the concentrations of many chemicals at the soil surface will decrease through the process of leaching. Therefore, over time the amount of chemical that is present at the surface will decrease (depending on rainfall), reducing the risk posed to the terrestrial receptors and human health at the land application site. This is linked to the risk posed to groundwater and adjacent surface waters, as the chemicals that show a higher degree of leaching will potentially pose greater aquatic risks.

To investigate the extent that leaching might affect the concentrations of chemicals remaining at the soil surface, the column leachate data (F1 to F4) were further evaluated. To do this, the concentrations of chemicals found in each leachate fraction were converted to concentrations released from the solid material (considering solid to liquid ratios). These released concentrations were then converted to a percentage of the total concentration present in the solid material. This gives an indication of how much of the total chemical present was release into each of the column fractions.

These calculations were performed using the aluminium, copper, manganese and zinc data from SE4 and SE5 and the results are summarised as averages in Figure 24. These metals were all identified as being high priority in the terrestrial environment (i.e. ecological and human exposures to the solid material). The leached percentages could not be calculated for the remaining high priority chemicals in the terrestrial environment for a range of reasons outlined below.

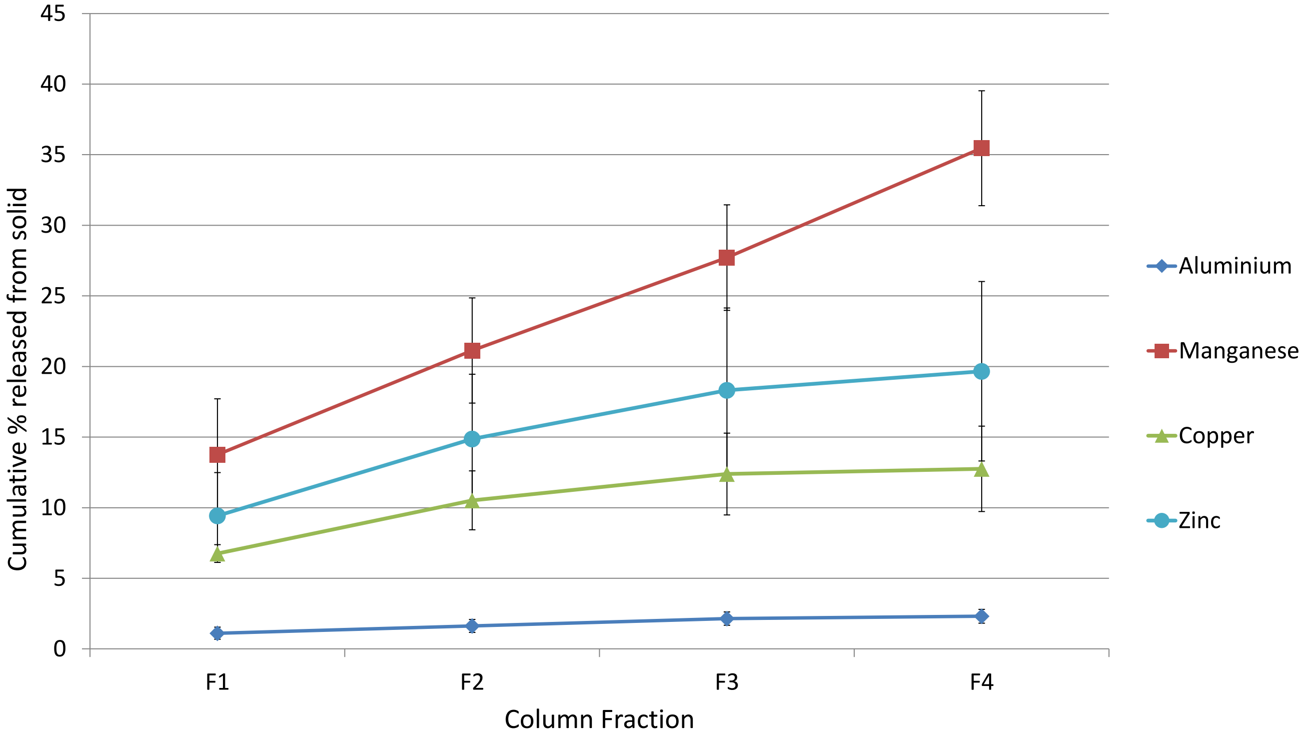


Figure 24: Cumulative percentages released from the MWOO into the four column leachate fractions (F1 to F4). Error bars indicate one standard error

For these chemicals, manganese and zinc released the highest proportion of the total concentration present into the leachates. The cumulative proportion released was approximately 35% and 20%, respectively. The higher leaching of these metals compared to the others is consistent with their lower Kd values (Table 21). The high leaching potential of these two metals was also identified when assessing their hazard in the leachates, with both manganese and zinc identified as high priority to at least one of the leachate receptors. The high concentrations of these metals leached from the material are likely to be due to the high complexation of these metals with the DOC in the leachates (DOC concentrations in F1 fraction were up to approximately 6 g/L). The association between metals and DOC in the leachates is discussed in more detail in Section 17.2.

Of the five metals evaluated, aluminium showed the lowest capacity to leach from the MWOO with only approximately 2.5% of the total concentrations removed by the leachates in all fractions combined. This is consistent with the high Kd value that was determined for aluminium (Table 21). This indicates that the terrestrial risks associated with the presence of aluminium in the solid material may be ongoing following land application of MWOO. This does not however indicate that aluminium will not be a potential risk in the leachates as it was also identified as high priority following Part III.

Figure 24 shows that for the metals there appears to be a plateau in the released concentrations, with the exception of manganese. This indicates that there is a readily leachable fraction of each of the metals and a more persistent fraction. This suggests that there is a fraction of these metals in the material that may be irreversible bound to the solid phase. If this is the case then, depending on the strength of binding, even though there is a fraction that may persist at the soil surface for a longer period of time this fraction may have low bioavailability. The bioavailability of metals in the MWOO solid material may be an area of future research that would allow for a better understanding of the likely ecological effects.

The summary of the column leachate data could not be undertaken for the remaining chemicals that were prioritised as high priority following Part III. For BPA, this was because no leachate data were available due to a lack of analytical methods. For the plasticisers (DEHA, DEHP and dibutyl phthalate) and DBT the concentrations in the leachate samples were below the LOQ for the vast majority of leachate samples. This is consistent with the hydrophobic nature of these chemicals and indicates that what is in the solid material is likely to remain at the soil surface as opposed to leaching into the lower soil profile.

For phenol, these calculations in most cases produced cumulative results (F1 to F4) greater than 100%. This is possibly due to the formation of phenol as a degradation product from other organic compounds, however, it does imply that the mobility of phenol is quite high. This suggests that phenol, which may be added to the soil through land application of MWOO, may not remain at the soil surface following a rainfall event, as it will be readily leached.

The column leachates were not analysed for the PBDE compounds, therefore this calculation could not be completed. The batch extractions from SE5 were however analysed for these compounds, therefore, this information can be used to give an indication of the proportion of the total concentration in the solid material that may be mobilised. This calculation was performed using the total PBDE concentrations only and did not consider the different congeners. For both facilities the proportion of the total PBDE concentration that was mobilised into these extractions ranged from < 0.002% to approximately 1%. This low proportion of mobilised PBDEs is likely due to the highly hydrophobic nature of these compounds. Due to this and the strong affinity of these compounds for organic carbon, the PBDEs that were measured in the leachates are likely to be bound to dissolved organic matter, which may reduce their bioavailability.

17 Bioavailability and speciation of chemicals in the environment

The assessment of the chemicals in this report has focussed only on the total concentrations of the chemicals in the MWOO solids and leachates (<0.8 µm or <0.45 µm depending on the analysis, see Section 3). However, in environmental samples, the total concentrations of chemicals are often an overestimation of what is actually available to be taken up by an organism. For ecological studies, bioavailability is defined as the contaminant fraction 'which is freely available to cross an organisms (cellular) membrane from the medium the organism inhabits at a given point in time.' Whereas, bioaccessibility encompasses what is actually bioavailable now plus what is 'potentially bioavailable' (McGrath and Semple, 2010). For human health, bioavailability refers to the proportion of a substance that reaches a target tissue and is able to have an effect. The bioavailability of chemicals to humans is taken into account in the derivation of guideline values, for example the HILs and the drinking water guidelines, therefore this aspect of bioavailability will not be expanded on here. This section will focus only on the ecological bioavailability of contaminants.

17.1 Effect of soil type on terrestrial toxicity and bioavailability

It is widely understood that the toxicity and bioavailability of metals in soils can be strongly influenced by variations in soil chemical and physical properties (Smolders et al., 2004). The specific soil properties that have been shown to play the greatest role in controlling the toxicity and bioavailability of metals are pH, clay content, organic carbon and CEC (Smolders et al., 2004, Oorts et al., 2006, Rooney et al., 2007, Heemsbergen et al., 2009, Li et al., 2011). Variations in these properties have been shown to result in changes in toxicity by up to three orders of magnitude compared to toxicity based on total metal concentrations (Smolders et al., 2004, Rooney et al., 2007, Li et al., 2011). The influence of soil type on the toxicity and bioavailability of metals in soils has been incorporated into the NEPM for several metals, and the selection of ACLs at a site is based on soil properties (as outlined in Section 5.1.1). This approach has also been implemented into the WA Biosolids Guidelines, where land application of biosolids can be limited by the soil properties at the application site.

In this study, the criteria concentrations for ecological exposure to the MWOO solid material were selected based on conservative assumptions for a range of soil properties. The assumptions used were that soil pH was 4.5 (in $CaCl_2$), CEC was 5 $cmol_c$/kg and clay was 1%. Based on these soil properties, ACLs were selected from the NEPM for zinc, copper, chromium and nickel that were ‘site-specific’ to be used as the criteria concentrations. Of these metals, zinc and copper a were categorised as being of high priority for terrestrial ecological receptors, therefore, they are used below to demonstrate the effect of soil type on the ACL, which is directly due to the effect of soil type on metal bioavailability.

The selection of ACLs based on soil properties is outlined in detail in Schedule B5c of the NEPM but the tables that were used to select the ACLs (and criteria concentrations) in this assessment for zinc and copper are shown in Table 24 to Table 25. The ACLs for these metals vary up to approximately 20-fold depending on soil properties. For all of these metals, even at the highest ACLs shown they would have had HQ$_{max}$ values greater than 1, however, the absolute value would have been considerably lower, which may result in a different final priority grouping for these metals.

Table 24: Soil specific added contaminant limits for fresh zinc contamination (urban residential and public open space) (Table 10, NEPM Schedule B5c)

pH	CEC (cmol$_c$/kg)					
	5	10	20	30	40	60
4.0	20	20	20	20	20	20
4.5	25	30	30	30	30	30
5.0	35	45	45	45	45	45
5.5	45	70	70	70	70	70
6.0	60	100	100	100	100	100
6.5	60	100	150	150	150	150
7.0	60	100	180	220	220	220
7.5	60	100	180	240	300	330

Table 25: Soil specific added contaminant limits for fresh copper contamination (urban residential and public open space) (Table 52, NEPM Schedule B5c) (note that the soil property that provides the lowest ACL should be used)

	CEC (cmol$_c$/kg)					
	5	10	20	30	40	60
CEC-based ACL	30	60	65	65	70	70
	pH					
	4.5	5.5	6.0	6.5	7.5	8.0
pH-based ACL	20	40	60	85	170	250

Using copper as an example, the assessment used a conservative criteria concentration of 20 mg/kg. This resulted in an HQ_{max} value of 83 and 100% of the samples with HQ > 1. For Cu, soil CEC and pH can be used to predict toxicity in soils (Table 25). If it is assumed that the soil has a pH of 8.0 then the ACL becomes 250 mg/kg (Table 25). As a result of this, the HQ_{max} value decreases to 6.7 and there are only 17% of the samples that exceed this criteria concentration. Using these assumptions and the scoring system outlined in Section 14.1, Cu would be categorised as low priority. This example demonstrates that although a range of metals have been categorised as being high priority from the detailed hazard assessment, the actual risk posed to the terrestrial environment following land application of MWOO will be dependent on soil type.

The speciation of aluminium in soils is also strongly related to soil properties and in particular soil pH. At pH less than 5, aluminium hydrolyses in solution and is predominately found as Al^{3+}, which is the most toxic Al species (Delhaize & Ryan, 1995). At soil pH between 5.5 and 8.5, aluminium is insoluble and therefore not bioavailable (Gensemer & Playle, 1999). Due to this, aluminium toxicity does not occur in soils within this pH range. The current RRE, which provides the requirements for land applying MWOO in NSW, does not allow application to soil with pH below 5, therefore the potential for aluminium toxicity is greatly reduced.

For non-ionic organic compounds, the primary soil property that is responsible for mitigating bioavailability and toxicity in soil is organic carbon. The partitioning of organic compounds between organic carbon and water can be summarised by the organic carbon water partitioning coefficient (Koc) and the higher this value is the more strongly bound a chemical will be to organic matter. For ionic organic compounds, other factors, for example, those outlined above for metals will also be important. This information needs to be considered when trying to understand the potential risks posed by organic compounds in the environment.

The information presented above briefly outlines the importance of soil type in assessing the risks associated with metals and organic compounds in soil following land application of waste. Based on this, further research is warranted investigating the effect of soil type on the risks associated with land application of MWOO.

17.2 Metal bioavailability and speciation in leachates

The bioavailability, and hence toxicity, of metals is affected by their chemical form (speciation). In particular, it is widely accepted that metals when bound to particles and natural organic matter (NOM) are not bioavailable. Understanding metal speciation is therefore critical to understanding the environmental risks from metal contamination.

Metal speciation is generally difficult to measure directly, and chemical speciation software packages are frequently used to estimate speciation. These models calculate speciation on the basis of laboratory-derived constants that are a measure of the strength of bonding interactions between metals and ligands. Ligands are chemical moieties that are capable of complexing metals, such as simple inorganic molecules or anions (e.g. chloride, carbonate, phosphate, ammonia), simple organic chemicals (e.g. citrate, oxalate) and more complex organic macromolecules commonly referred to as NOM (e.g. humic and fulvic acids, tannins and lignins).

Some speciation models are also able to estimate the speciation of redox sensitive metals under different redox conditions. The term ‘redox’ refers to the chemical transfer of electrons. In environmental samples the redox potential of water is commonly linked to how much dissolved oxygen is present. Being able to predict the redox speciation of metals is very useful in assessing risks. For example, in oxygenated surface waters, arsenic generally occurs as arsenate (AsO_4^{3-}) whereas in anoxic groundwater it predominantly exists as arsenite ($As(OH)_3$). Knowing the arsenic speciation is critical to issues related to contamination and remediation, as arsenite is more mobile and bioavailable than arsenate.

Despite the usefulness of speciation models, there are a number of limitations that need to be considered when interpreting model outputs. Of considerable importance is that speciation models generally assume the system is at equilibrium and do not take into account reaction kinetics (i.e. the rate of reactions). This can be a problem in situations when equilibrium is not reached (for example, mixing of waters with different chemical constituents, or in biological systems). It is possible that the MWOO leachates generated for this study were undergoing ongoing biogeochemical processes and were not at equilibrium. For example, sulfate reducing bacteria in the leachates may have been actively converting sulfate to sulfide. For these and other reasons, it is best to use the modelling outputs only to identify important processes that are influencing metal speciation in the leachates, as opposed to quantitative comparison with guideline values.

For this study, speciation modelling was used to further assess the exposure of ecological receptors to metals in leachates. This was conducted using all of the metals that were identified as being high priority from Part III.

17.2.1 Metal speciation modelling approach

Visual MINTEQ, Version 3.0 was used to estimate the speciation of metals in leachates obtained from MWOO material from the two facilities. Measured data from SE5 F1 column leachate samples were used (Appendix C). Only one set of leachate data was available for each facility, nevertheless a qualitative assessment of the results should be broadly applicable to MWOO leachates in general. This is evidenced by comparable speciation results for leachates from MWOO produced by the two facilities (see below). Visual MINTEQ was used with default databases for inorganic and organic complexation. The effect of different temperatures (10 and 22 °C) on metal speciation was tested, as temperature can affect mineral precipitation and dissolution. There was no significant effect on metal speciation (data not shown). All results discussed below are for speciation calculations made at 22 °C.

As a cross check of the speciation predictions using Visual MINTEQ, speciation modelling of the leachate data from one facility was performed using WHAM7. WHAM7 uses a different (and well validated) approach to modelling organic complexation of metals and provides a useful comparison to the calculations obtained from Visual MINTEQ. Differences in organic complexation calculated by the two models agreed to within 10 % with some minor exceptions. This is discussed in more detail in Appendix C.

17.2.2 Metal complexation and adsorption

Using the metal concentrations in the leachate samples, preliminary modelling was conducted to determine the dominate oxidation states of redox sensitive metals (all data shown in Appendix C). Following this, the binding of metals onto NOM or mineral phases was modelled. Binding of metals onto soil mineral phases in the leachate was accounted for by modelling adsorption to hydrous ferric oxide (HFO) using the default Visual MINTEQ parameters for concentration of binding sites. HFO is regarded as the most important mineral binding phase for metals in geochemical systems, largely because of its extremely high surface area (600 m^2/g). The HFO concentration used to represent typical soil porewater was 650 mg/L. This was based on typical soil properties (porosity, bulk density and HFO solid concentration (see Appendix C for details). Additional modelling at 1 mg/L HFO (indicative of the leachates only) and an intermediate HFO concentration of 65 mg/L was also conducted (see Appendix C). This modelling was done at a redox value of Eh = 0 and at the measured pH of the leachate (pH = 6.7). The effect of redox and pH on speciation is discussed in Section 17.2.3.

Following modelling of metal binding to NOM and mineral phases, the amount of each metal present as dissolved inorganic species (e.g. free ions or metal sulfide complexes in solution) was calculated. This was done by subtracting the bound concentrations (NOM and HFO) from the total concentration.

Results summarising metal complexation and adsorption for leachate from Facility B are summarised in Table 26. The results for the two facilities were extremely similar, so only one set of results has been shown for brevity. The similarity between results for the two facilities is not surprising given the similar water chemistry for the two leachates.

Only results for metals identified as high priority in Part III are included here, but modelling results for other metals and are included in the Appendix C. Results for metal binding with 1 mg/L and 65 mg/L of HFO are also shown in Appendix C. Note that Visual MINTEQ does not have appropriate constants in the default database for NOM interactions with tin, hence the 'organic' tin cannot be estimated. Therefore, despite being identified as a high priority in Part III, tin has been excluded from these results. Results for the modelled distribution between Sn(II) and Sn(IV) species, and any mineral adsorption, are included in Appendix C.

In Table 26, 'Total' refers to the total concentrations calculated by Visual MINTEQ based on the measured filtered concentration in the leachate but considering the redox speciation. The preliminary modelling of redox states found that Co(III) and Cr(VI) accounted for less than 0.1 % of the measured total cobalt and chromium, respectively, therefore, these redox species have not been included (see Appendix C). 'Organic' refers to the percentage bound to NOM. 'Mineral (HFO)' refers to the percentage adsorbed into mineral surfaces (in this case HFO). 'Dissolved inorganic' refers to the dissolved inorganic fraction calculated by subtracting the adsorbed fractions from the total (100%). The dissolved inorganic fraction can be regarded as a conservative measure of what fraction of the metals may be bioavailable (discussed further below).

Table 26: Modelled organic complexation and mineral adsorption at Eh = 0 mV and pH = 6.7. See text for column heading definitions

Metal species	'Total' (µg/L)	Adsorbed		Dissolved inorganic (%)
		Organic (%)	Mineral (HFO) (%)	
Al	12000	100.0	0.0	0.0
Ba	179.1	71.8	0.5	27.8
Cd	20.0	100.0	0.0	0.0
Co(II)	69.8	96.2	0.3	3.5
Cr(III)	120.0	100.0	0.0	0.0
Cu	1100	100.0	0.0	0.0
Fe(II)	24.7	100.0	0.0	0.0
Fe(III)	16978	100.0	0.0	0.0
Hg	0.1	100.0	0.0	0.0
Ni	498.3	98.9	0.3	0.8
Pb	99.2	99.2	0.8	0.0
Zn	7037	97.7	2.3	0.0

The modelling suggests that complexation by NOM heavily dominates (> 95 – 100 %) the speciation of all of the metals in Table 26 except barium for which approximately 70% was associated with NOM. This result is in keeping with the extremely high concentration of NOM in the leachate (> 6 g/L DOC). It is worth noting that aged aquatic NOM has been used to validate Visual MINTEQ, which is likely to have a lower binding affinity for metals compared to terrestrially derived NOM (Richards et al., 2001). Based on this, the modelling of metal complexation with NOM provided by MINTEQ is likely to underestimate the actual degree of metal binding in this freshly derived NOM from MWOO.

The proportion of metals in Table 26 adsorbed to mineral phases (HFO) was trivial in most cases. Mineral adsorption may still be an important process in further reducing the dissolved inorganic concentration of these metals. In terms of ecological impacts, this may be especially significant where the leachate metal concentrations are very high (e.g. zinc). Mineral adsorption is also expected to be an important factor in limiting dissolved arsenic concentrations (see Appendix C).

17.2.3 Effect of pH and redox on speciation

Additional speciation modelling was conducted to investigate the effect of varying pH and redox conditions on the proportion of dissolved inorganic (i.e. bioavailable) species. This was done using a range of pH (pH = 5.0, 6.7 and 8.0) and redox (Eh = -200, 0 and +400 mV) values to represent a range of soil conditions. These are key variables that affect metal speciation in soil porewaters. For example, under different pH and redox conditions, chromium can exist as either Cr(III) or Cr(VI).

Dissolved inorganic concentrations of selected metal species at different pH and Eh values are shown in Table 27. The calculated proportions of aluminium, chromium (Cr(III)), copper, iron and mercury were too low to assess any trends, as a consequence of strong association with NOM. Therefore these metals have been omitted from the table.

Table 27: The proportions (%) of dissolved inorganic metal (compared to the total dissolved concentration) in leachate modelled under different redox and pH conditions. Eh values are shown in mV.

Metal species	pH 6.7			Eh = 0		
	Eh = -200	Eh = 0	Eh = +400	pH = 5.0	pH = 6.7	pH = 8.0
Ba	28.2	28.2	28.2	42.3	28.2	19.1
Cd	99.9	0.0	0.0	0.5	0.0	0.0
Co(II)	64.8	3.9	3.9	8.4	3.9	1.9
Ni	44.2	1.1	1.1	2.3	1.1	0.6
Pb	99.5	0.0	0.0	0.0	0.0	0.0
Zn	84.6	1.6	1.6	6.6	1.6	0.2

The proportion of dissolved inorganic barium was unaffected by changes in redox potential (Eh) but decreased with increasing pH. This is a consequence of lower competition for binding sites from H^+ at higher pH values. The metals cadmium, cobalt, nickel, lead and zinc generally had higher dissolved inorganic concentrations under reducing redox conditions and at lower pH. To some extent the effect with pH can be explained by increased competition for NOM binding sites from H^+ at lower pH (as with barium). The effect with decreasing redox potential is better explained by the formation of metal sulfide complexes in solution, as indicated by the Visual MINTEQ modelling (data not shown). These metal sulfide complexes are generally considered as being unlikely to be bioavailable to aquatic organisms. Therefore, the changes that occur in the speciation of these metals at low Eh are likely to have little consequence on the overall bioavailability (and hence toxicity) of these metals.

17.2.4 Interpretation of speciation results

The modelled data provide evidence that, for many metals, complexation by NOM and to some extent adsorption to mineral phases will significantly limit the concentrations of dissolved inorganic metal species in MWOO leachates. This means that concentrations of bioavailable metal will be considerably lower than measured concentrations in the leachates. For some metals, this may be enough to reduce the degree of concern from high priority to medium or even low priority, but a low proportion of dissolved inorganic metal still needs to be interpreted in the context of very high metal concentrations (in some cases). In other words, despite the majority of metal being bound to NOM or mineral phases, there may still be enough residual bioavailable inorganic species to exceed toxicity thresholds. It is also important to remember that metals cannot be degraded. For repeat applications of MWOO, load considerations would have to be taken into account.

The metals identified as being of high priority in leachates for the ecological receptors in Part III of this report were aluminium, barium, cadmium, chromium, cobalt, copper, iron, lead, mercury, nickel, tin, and zinc. When modelling was conducted in a simulated soil porewater with Eh = 0, the percentage of dissolved inorganic metal was <0.1 % for aluminium, cadmium, chromium, copper, iron, lead, mercury, and zinc. This finding is consistent with the TIE results that indicated other contaminants as the main contributors to acute ecotoxicity. Site-specific soil conditions, and the potential effects of key environmental factors such as pH and Eh, would need to be considered to have a better understanding of what is required to ensure the safe land application of MWOO. For example, the modelling showed that concentrations of bioavailable metals are expected to increase at lower pH. This means that it would be unwise to apply MWOO material where acid sulfate soils are present, or where other factors may give rise to acidic soils. In addition, changes in pH and Eh during leachate transport may result in the release of NOM-bound metals.

The metals with significant fractions of dissolved inorganic species (barium (28 %), cobalt (3.5 %) and nickel (0.8 %) require further consideration of their ecotoxicity. The speciation of tin could not be adequately modelled by Visual MINTEQ using the default database. Further consideration of the speciation of tin would be needed to better understand the risk of impacts from tin.

18 Physical and geological factors effecting leachate transport and dilution

18.1 Effect of soil type on bulk movement of leachates

The physical properties of the soil profile can have a significant effect on the ease that water can move through a soil profile, via pore spaces and fractures (i.e. the soil hydraulic conductivity). In the case of land applied MWOO, this will have an influence on what chemical loads may reach groundwater. Soil hydraulic conductivity is determined by soil profile characteristics including soil moisture, texture, structure (e.g. porosity) and profile type (e.g. duplex or uniform profile). In a soil that has high hydraulic conductivity (e.g. sandy soil), the water is able to move through the profile quicker, resulting in more leachate reaching groundwater. This will also allow less contact time with soil particles therefore decreasing the possible attenuation of chemicals through adsorption to the solid phase in the soils. In addition to the soil type, the local rainfall and infiltration rate will affect the amount of water that is in the soil and the time taken for contaminants to transport vertically from the application area down to the groundwater table.

These aspects and the likely effects are all site specific and should be considered, along with depth to groundwater, to allow safe land application of MWOO. To show the effect of soil type on the movement of water through a soil profile, Table 28 summarises the expected hydraulic conductivity in some different soils (FAO, 2007). As expected, the hydraulic conductivity in a heavy clay is considerably slower than what would be expected in a sandy soil. This may alter the risk posed to groundwater and surface water from leachates following land application of MWOO.

Table 28: Summary of hydraulic conductivity in different textured soils

Soil texture	Hydraulic conductivity (m/d)
Heavy clay	0.01 – 0.05
Clay, silty loam	0.01 – 0.4
Light clay loam	0.3 – 1.0
Sandy loam	1.0 – 3.0
Loamy sand, fine sand	1.6 – 6.0
Medium to coarse sand	> 6

18.2 Dilution and attenuation in a groundwater aquifer

The aquifer characteristics underlying a site where MWOO has been applied will also have an influence on the concentrations of chemicals that may reach off-site receptors (e.g. surface water or groundwater bores). Generally, advective transport is the dominant process controlling any subsurface movement of contaminants, however, diffusion and dispersion may also take place. The dilution and attenuation of a chemical in a groundwater aquifer depends on the interaction of a number of site-specific factors and physical and biochemical processes. Leachate that moves through a soil profile and reaches an aquifer will mix with groundwater, reducing the total concentration. The amount of dilution and resulting groundwater concentration can be calculated with a dilution-attenuation factor (DAF). The DAF can be calculated for a site using the following equation:

$$DAF = 1 + \frac{Kid}{IL}$$

where *i* is the gradient (m/m), *d* is the mixing zone depth (m), *I* is the infiltration rate (m/yr), *L* is the length of area of concern parallel to groundwater flow (m) and *K* is the aquifer hydraulic conductivity (USEPA, 1996). These parameters are all site-specific, however, the USEPA suggest a default DAF of 20 based on a range of assumptions (USEPA, 1996). The actual groundwater concentrations directly under the application area can then be determined using the following equation:

$$C_{gw} = \frac{C_l}{DAF}$$

where C_{gw} is the groundwater concentration in the mixing zone (mg/L) and C_l is the soil pore water concentration entering the mixing zone. In the case of land applied MWOO, the soil pore water concentrations can be predicted based on the soil solution partitioning of each chemical.

These equations do not take into account any chemical processes that may take place. During potential transport from the application area to the groundwater table directly below and through an aquifer, processes such as dispersion, adsorption (desorption) and degradation can further attenuate actual concentrations reaching the groundwater table directly below. These attenuating factors together with additional dilution also affects transport from groundwater directly below the application area to nearby bores or surface waters some distance away.

For future evaluation of the data collected from this project, this DAF approach may be used along with predicted soil porewater concentrations to assist in the development of MWOO application rates that will be protective of groundwater. The chemicals identified through Part III should be the initial focus of this work.

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Appendix A - summary of analytical data

Table A1: Summary of chemical analysis of mixed waste organic outputs from Facility A

Chemical group	CAS Number	Chemical	No. of samples	No. detects (% Detects)	Average[1]	Minimum	Maximum	Median[1]	95th percentile[1]
Metals (mg/kg)	7429-90-5	Aluminium	64	64 (100)	5500	4100	21000	5200	7100
	7440-36-0	Antimony	64	44 (69)	12	<3.1	160	4.6	27
	7440-38-2	Arsenic	64	64 (100)	4.8	3.0	7.9	4.5	6.7
	7440-39-3	Barium	64	64 (100)	130	90	230	120	170
	7440-41-7	Beryllium	64	52 (81)	0.15	<0.1	0.21	0.15	0.18
	7440-42-8	Boron	64	62 (97)	21	<11	33	22	28
	7440-43-9	Cadmium	64	63 (98)	2.0	<0.52	5.1	2.0	3.2
	7440-47-3	Chromium	64	64 (100)	52	34	160	51	63
	7440-48-4	Cobalt	64	64 (100)	5.4	3.3	51	4.4	6.7
	7440-50-8	Copper	64	64 (100)	720	89	9100	210	3800
	7439-89-6	Iron	64	64 (100)	7500	5000	14000	7500	9900
	7439-92-1	Lead	64	64 (100)	270	160	1000	250	380
	7439-93-2	Lithium	64	54 (84)	2.5	<2.1	3.1	2.4	2.8
	7439-96-5	Manganese	64	64 (100)	250	180	1300	240	280
	7439-97-6	Mercury	64	61 (95)	0.25	<0.02	0.53	0.26	0.48
	7439-98-7	Molybdenum	64	64 (100)	6.4	2.4	120	4.7	6.5
	7440-02-0	Nickel	64	64 (100)	120	15	2900	25	400
	7782-49-2	Selenium	64	0 (0)		<3.0	<3.4		
	7440-22-4	Silver	64	61 (95)	1.6	<0.52	6.7	1.3	2.6
	7440-24-6	Strontium	64	64 (100)	100	68	490	85	150
	7704-34-9	Sulfur	64	64 (100)	3100	2400	3900	3100	3600
	7440-28-0	Thallium	64	0 (0)		<1.0	<1.1		
	7440-31-5	Tin	64	64 (100)	16	7.5	38	15	23
	7440-32-6	Titanium	64	64 (100)	86	55	170	82	120
	7440-62-2	Vanadium	64	64 (100)	9.6	6.4	22	9.3	13
	7440-66-6	Zinc	64	64 (100)	640	270	5100	480	1400
Major cations (g/kg)	7440-70-2	Calcium	64	64 (100)	27	22	32	27	32
	7439-95-4	Magnesium	64	64 (100)	2.0	1.5	2.4	2.0	2.3

Chemical group	CAS Number	Chemical	No. of samples	No. detects (% Detects)	Average[1]	Minimum	Maximum	Median[1]	95th percentile[1]
	7440-09-7	Potassium	64	64 (100)	5.6	3.7	6.7	5.7	6.3
	7440-23-5	Sodium	64	64 (100)	6.6	4.7	9.0	6.5	8.2
PAHs (mg/kg)	83-32-9	Acenaphthene	64	2 (3)	0.35	<0.12	<0.81[a]		
	208-96-8	Acenaphthylene	64	0 (0)		<0.12	<0.81		
	120-12-7	Anthracene	64	0 (0)		<0.12	<0.81		
	56-55-3	Benzo (a) anthracene	64	0 (0)		<0.12	<0.81		
	50-32-8	Benzo (a) pyrene	64	0 (0)		<0.12	<0.81		
	205-99-2	Benzo (b) fluoranthene	64	0 (0)		<0.12	<0.81		
	191-24-2	Benzo (ghi) perylene	64	0 (0)		<0.12	<0.81		
	207-08-9	Benzo (k) fluoranthene	64	0 (0)		<0.12	<0.81		
	218-01-9	Chrysene	64	0 (0)		<0.12	<0.81		
	53-70-3	Dibenzo (ah) anthracene	64	0 (0)		<0.12	<0.81		
	206-44-0	Fluoranthene	64	11 (17)	0.23	<0.13	0.36	0.2	0.34
	86-73-7	Fluorene	64	2 (3)	0.23	<0.12	0.25		
	193-39-5	Indeno (123cd) pyrene	64	0 (0)		<0.12	<0.81		
	91-20-3	Naphthalene	64	43 (67)	0.47	<0.14	0.71	0.45	0.66
	85-01-8	Phenanthrene	64	33 (52)	0.38	<0.13	0.65	0.38	0.54
	129-00-0	Pyrene	64	8 (13)	0.23	<0.13	0.33	0.21	0.31
Phenols (mg/kg)	58-90-2	2,3,4,6-Tetrachlorophenol	64	0 (0)		<0.37	<2.4		
	95-95-4	2,4,5-Trichlorophenol	64	0 (0)		<0.62	<4.0		
	88-06-2	2,4,6-Trichlorophenol	64	0 (0)		<0.25	<1.6		
	120-83-2	2,4-Dichlorophenol	64	0 (0)		<1.2	<8.1		
	105-67-9	2,4-Dimethylphenol	64	0 (0)		<3.1	<20		
	51-28-5	2,4-Dinitrophenol	64	0 (0)		<3.7	<24		
	121-14-2	2,4-Dinitrotoluene	64	0 (0)		<0.25	<1.6		
	87-65-0	2,6-Dichlorophenol	64	0 (0)		<0.25	<1.6		
	95-57-8	2-Chlorophenol	64	0 (0)		<0.37	<2.4		
	534-52-1	2-Methyl-4,6-dinitrophenol	64	0 (0)		<1.9	<12		
	95-48-7	2-Methylphenol	64	0 (0)		<0.62	<4.0		

Chemical group	CAS Number	Chemical	No. of samples	No. detects (% Detects)	Average[1]	Minimum	Maximum	Median[1]	95th percentile[1]
	88-75-5	2-Nitrophenol	64	0 (0)		<0.37	<2.4		
	108-39-4 and 106-44-5	3+4-Methylphenol	64	52 (81)	3.7	<0.68	9.1	3.2	7.8
	59-50-7	4-Chloro-3-methylphenol	64	0 (0)		<0.62	<4.0		
	100-02-7	4-Nitrophenol	64	0 (0)		<2.5	<16		
	87-86-5	Pentachlorophenol	64	0 (0)		<0.62	<4.0		
	108-95-2	Phenol	64	64 (100)	26	4.8	85	19	62
Phthalates (mg/kg)	85-68-7	Benzyl butyl phthalate	20	2 (10)	3.6	<0.25	5.7		
	103-23-1	Bis-2-ethylhexyl adipate	16	16 (100)	24	3.6	52	9.8	51
	117-81-7	Bis-2-ethylhexyl phthalate	64	64 (100)	180	68	2600	130	190
	84-74-2	Dibutyl phthalate	64	53 (83)	6.2	0.68	18	4.3	12
	84-66-2	Diethyl phthalate	20	0 (0)		<0.25	<3.0		
	131-11-3	Dimethyl phthalate	20	1 (5)	0.42	<0.25	<3.0[b]		
	117-84-0	Di-n-octyl phthalate	20	2 (10)	42	<0.25	82		
Chlorobenzenes (mg/kg)	634-66-2	1,2,3,4-Tetrachlorobenzene	64	0 (0)		<0.37	<2.4		
	95-94-3	1,2,4,5-Tetrachlorobenzene	64	0 (0)		<0.25	<1.6		
	120-82-1	1,2,4-Trichlorobenzene	64	0 (0)		<0.37	<2.4		
	95-50-1	1,2-Dichlorobenzene	64	0 (0)		<0.37	<2.4		
	106-46-7	1,4-Dichlorobenzene	64	0 (0)		<0.37	<2.4		
	118-74-1	Hexachlorobenzene	62	0 (0)		<0.06	<0.81		
	608-93-5	Pentachlorobenzene	64	0 (0)		<0.12	<0.81		
Nitrobenzenes (mg/kg)	98-95-3	Nitrobenzene	64	0 (0)		<0.12	<0.81		
	82-68-8	Pentachloronitrobenzene	64	0 (0)		<0.25	<1.6		
Pesticides (mg/kg)	309-00-2	Aldrin	60	0 (0)		<0.01	<1.6		
	584-79-2	Allethrin	22	0 (0)		<0.07	<3.9		
	319-84-6	alpha-BHC	60	0 (0)		<0.01	<0.81		
	5103-71-9	alpha-Chlordane	60	0 (0)		<0.01	<0.81		
	834-12-8	Ametryn	22	0 (0)		<0.14	<1.5		

Chemical group	CAS Number	Chemical	No. of samples	No. detects (% Detects)	Average[1]	Minimum	Maximum	Median[1]	95th percentile[1]
	1610-17-9	Atraton	22	0 (0)		<0.34	<3.8		
	1912-24-9	Atrazine	39	1 (3)	0.011	<0.005	<3.1[c]		
	131860-33-8	Azoxystrobin	22	0 (0)		<0.004	<0.009		
	319-85-7	beta-BHC	60	0 (0)		<0.01	<0.81		
	92880-79-0	Bifenthrin	22	0 (0)		<0.07	<0.77		
	28434-01-7	Bioresmethrin	22	0 (0)		<0.07	<0.77		
	56073-10-0	Brodifacoum	24	0 (0)		<0.01	<0.10		
	786-19-6	Carbophenothion	22	0 (0)		<0.07	<0.77		
	5234-68-4	Carboxin	22	0 (0)		<0.004	<0.009		
	2921-88-2	Chlorpyrifos	26	0 (0)		<0.07	<0.17		
	61949-76-6	cis-Permethrin	22	0 (0)		<0.07	<0.77		
	7700-17-6	Crotoxyphos	22	0 (0)		<0.07	<0.77		
	68359-37-5	Cyfluthrin	22	0 (0)		<0.16	<1.8		
	52315-07-8	Cypermethrin	22	0 (0)		<0.16	<1.8		
	319-86-8	delta-BHC	60	0 (0)		<0.01	<0.81		
	52918-63-5	Deltamethrin	22	0 (0)		<0.16	<1.8		
	333-41-5	Diazinon	11	0 (0)		<0.07	<0.77		
	1085-98-9	Dichlofluanid	24	0 (0)		<0.01	<0.04		
	62-73-7	Dichlorvos	22	0 (0)		<0.07	<0.77		
	60-57-1	Dieldrin	60	0 (0)		<0.01	<0.81		
	119446-68-3	Difenoconazole	22	0 (0)		<0.01	<0.02		
	60-51-5	Dimethoate	39	0 (0)		<0.01	<0.77		
	121124-29-6	Emamectin B1a	22	0 (0)		<0.006	<0.01		
	121424-52-0	Emamectin B1b	22	0 (0)		<0.006	<0.01		
	155569-91-8	Emamectin Benzoate	2	0 (0)		<0.10	<0.10		
	959-98-8	Endosulfan I	58	1 (2)	0.065	<0.01	<1.6[d]		
	33213-65-9	Endosulfan II	60	0 (0)		<0.01	<1.6		
	1031-07-8	Endosulfan sulfate	60	0 (0)		<0.01	<1.6		
	72-20-8	Endrin	60	0 (0)		<0.01	<1.6		
	7421-93-4	Endrin aldehyde	27	0 (0)		<0.39	<0.45		
	53494-70-5	Endrin ketone	37	0 (0)		<0.26	<1.6		

Chemical group	CAS Number	Chemical	No. of samples	No. detects (% Detects)	Average[1]	Minimum	Maximum	Median[1]	95th percentile[1]
	563-12-2	Ethion	22	0 (0)		<0.07	<0.77		
	56-38-2	Ethyl parathion	22	0 (0)		<0.16	<1.8		
	22224-92-6	Fenamiphos	22	0 (0)		<0.41	<4.6		
	122-14-5	Fenitrothion	22	0 (0)		<0.07	<0.77		
	55-38-9	Fenthion	22	0 (0)		<0.07	<0.77		
	51630-58-1	Fenvalerate	22	0 (0)		<0.16	<1.8		
	120068-37-3	Fipronil	22	3 (14)	0.018	<0.02	<0.026[e]	0018	0.021
	79241-46-6	Fluazifop-p-butyl	22	0 (0)		<0.006	<0.01		
	131341-86-1	Fludioxonil	22	0 (0)		<0.06	<0.12		
	136426-54-5	Fluquinconazole	22	0 (0)		<0.02	<0.04		
	58-89-9	gamma-BHC	61	0 (0)		<0.01	<0.81		
	5103-74-2	gamma-chlordane	60	1 (6)	0.12	<0.01	<0.81[f]		
	76-44-8	Heptachlor	60	0 (0)		<0.01	<0.81		
	66240-71-9	Heptachlor epoxide	60	0 (0)		<0.01	<0.81		
	51235-04-2	Hexazinone	22	0 (0)		<0.14	<1.5		
	138261-41-3	Imidacloprid	22	0 (0)		<0.02	<0.04		
	144171-61-9	Indoxacarb	22	0 (0)		<0.02	<0.04		
	465-73-6	Isodrin	64	0 (0)		<0.25	<1.6		
	91465-08-6	l-Cyhalothrin	22	0 (0)		<0.07	<0.77		
	121-75-5	Malathion	22	0 (0)		<0.07	<0.77		
	57837-19-1	Metalaxyl	22	1 (5)	0.011	<0.004	0.011		
	950-37-8	Methidation	22	0 (0)		<0.07	<0.77		
	72-43-5	Methoxychlor	68	0 (0)		<0.01	<1.6		
	86-50-0	Methyl azinphos	22	0 (0)		<0.07	<0.77		
	5598-13-0	Methyl chlorpyrifos	22	0 (0)		<0.07	<0.77		
	298-00-0	Methyl parathion	22	0 (0)		<0.16	<1.8		
	7786-34-7	Mevinphos	22	0 (0)		<0.07	<0.77		
	42874-03-3	Oxyfluorfen	17	0 (0)		<0.41	<9.0		
	298-02-2	Phorate	22	0 (0)		<0.07	<0.77		
	72-54-8	pp-DDD	60	0 (0)		<0.01	<0.81		
	72-55-9	pp-DDE	60	0 (0)		<0.01	<0.81		

Chemical group	CAS Number	Chemical	No. of samples	No. detects (% Detects)	Average[1]	Minimum	Maximum	Median[1]	95th percentile[1]
	50-29-3	pp-DDT	60	0 (0)		<0.01	<0.81		
	41198-08-7	Profenofos	22	0 (0)		<0.16	<1.8		
	1610-18-0	Prometon	22	0 (0)		<0.14	<1.5		
	7287-19-6	Prometryn	40	0 (0)		<0.003	<4.6		
	2312-35-8	Propargite	35	0 (0)		<0.009	<7.5		
	139-40-2	Propazine	22	0 (0)		<0.14	<1.5		
	31218-83-4	Propetamphos	22	0 (0)		<0.07	<0.77		
	122-34-9	Simazine	39	0 (0)		<0.02	<2.3		
	1014-70-6	Simetryn	22	0 (0)		<0.14	<1.5		
	35400-43-2	Sulprofos	22	0 (0)		<0.07	<0.77		
	107534-96-3	Tebuconazole	22	0 (0)		<0.41	<9.2		
	34014-18-1	Tebuthiuron	22	0 (0)		<0.14	<1.5		
	5915-41-3	Terbuthylazine	22	0 (0)		<0.14	<1.5		
	886-50-0	Terbutryn	22	0 (0)		<0.14	<1.5		
	22248-79-9	Tetrachlorvinphos	22	0 (0)		<0.16	<1.8		
	148-79-8	Thiabendazole	22	20 (91)	0.028	<0.007	0.051	0.027	0.047
	153719-23-4	Thiamethoxam	22	0 (0)		<0.007	<0.02		
	59669-26-0	Thiodicarb	22	0 (0)		<0.008	<0.02		
	61949-77-7	trans-Permethrin	22	3 (14)	0.56	<0.07	0.6	0.56	0.59
Herbicides (mg/kg)	93-76-5	2,4,5-T	46	0 (0)		<0.08	<1.6		
	93-72-1	2,4,5-TP	46	0 (0)		<0.03	<0.70		
	94-75-7	2,4-D	46	3 (7)	0.25	<0.04	<2.2[g]	0.16	0.42
	94-82-6	2,4-DB	46	0 (0)		<0.03	<1.1		
	1918-00-9	Dicamba	46	38 (85)	0.12	<0.06	<0.62[h]	0.12	0.18
	88-85-7	Dinoseb	46	0 (0)		<0.62	<0.83		
	1071-83-6	Glyphosate	6	0 (0)		<1.3	<1.5		
	94-74-6	MCPA	46	45 (98)	0.75	0.36	1.8	0.63	1.5
	93-65-2	MCPP	25	25 (100)	0.10	0.03	0.17	0.10	0.16
	1918-02-1	Picloram	42	0 (0)		<0.07	<1.6		
	55335-06-3	Triclopyr	46	0 (0)		<0.08	<0.82		

Chemical group	CAS Number	Chemical	No. of samples	No. detects (% Detects)	Average[1]	Minimum	Maximum	Median[1]	95th percentile[1]
PCBs (mg/kg)	12674-11-2	Aroclor 1016 (screen)	54	0 (0)		<0.53	<3.2		
	11104-28-2	Aroclor 1221 (screen)	38	0 (0)		<0.53	<3.2		
	11141-16-5	Aroclor 1232 (screen)	54	0 (0)		<0.53	<3.2		
	53469-21-9	Aroclor 1242 (screen)	54	0 (0)		<0.53	<3.2		
	12672-29-6	Aroclor 1248 (screen)	54	0 (0)		<0.53	<3.2		
	11097-69-1	Aroclor 1254 (screen)	54	0 (0)		<0.53	<3.2		
	11096-82-5	Aroclor 1260 (screen)	54	0 (0)		<0.53	<3.2		
PCBS (mg/kg)	12674-11-2	Aroclor 1016	15	0 (0)		<0.01	<0.59		
	11104-28-2	Aroclor 1221	15	0 (0)		<0.01	<0.59		
	11141-16-5	Aroclor 1232	15	0 (0)		<0.01	<0.59		
	53469-21-9	Aroclor 1242	15	0 (0)		<0.01	<0.59		
	12672-29-6	Aroclor 1248	15	0 (0)		<0.01	<0.59		
	11097-69-1	Aroclor 1254	15	0 (0)		<0.01	<0.59		
	11096-82-5	Aroclor 1260	15	0 (0)		<0.01	<0.59		
Alkylphenols (mg/kg)	1806-26-4	4-octylphenol	12	4 (33)	0.40	<0.08	0.58	0.50	0.57
	84852-15-3	4-nonylphenol	12	12 (100)	3.9	1.5	5.7	4.6	5.6
	140-66-9	4-tert-octylphenol	12	0 (0)		<0.04	<0.12		
	80-05-7	Bisphenol A	12	12 (100)	18	14	27	17	25
Organotins (µg/kg)	78763-54-9	Monobutyl Tin	7	7 (100)	17	1.7	37	19	35
	1191-48-6	Dibutyl Tin	7	7 (100)	16	2.2	28	20	28
	688-73-3	Tributyl Tin	7	5 (67)	2.6	<0.5	5.8	1.7	5.0
PBDEs (µg/kg)	N/A	Total PBDEs	6	6 (100)	120000	3800	720000	6100	540000
	N/A	Tri-BDE	6	6 (100)	33	2.4	180	4.1	130
	N/A	Tetra-BDE	6	6 (100)	250	28	1300	48	980
	N/A	Penta-BDE	6	6 (100)	190	32	640	68	550
	N/A	Hexa-BDE	6	6 (100)	20000	23	120000	170	87000
	N/A	Hepta-BDE	6	6 (100)	57000	62	330000	590	250000

Chemical group	CAS Number	Chemical	No. of samples	No. detects (% Detects)	Average[1]	Minimum	Maximum	Median[1]	95th percentile[1]
	N/A	Octa-BDE	6	6 (100)	34000	59	200000	590	150000
	N/A	Nona-BDE	6	6 (100)	10000	280	58000	510	44000
	N/A	Deca-BDE	6	6 (100)	4200	3000	7500	3500	6800
Perfluorinated compounds (µg/kg)	1763-23-1	PFOA	1	0 (0)		<1	<1		
	335-67-1	PFOS	1	0 (0)		<3	<3		
Nutrients (g/kg)	N/A	TKN	13	13 (100)	15	12	17	15	17
	7723-14-0	Phosphorus	64	64 (100)	3.5	2.7	4.9	3.5	4.0
Other	N/A	Asbestos (g/kg)	6	0 (0)		<0.1	<0.1		
	N/A	Conductivity (dS/m)	22	22 (100)	8.4	6.2	9.5	8.8	9.4
	N/A	pH (water)	22	22 (100)	6.6	6.0	7	6.6	7.0
	N/A	TOC (% Carbon)	17	17 (100)	34	28	43	33	42

[1] only concentrations that were above the limit of quantification were used to calculate the average, median and 95th percentile concentrations

Maximum measured concentration of:
[a] acenapthene = 0.41 mg/kg
[b] dimethyl phthalate = 0.42 mg/kg
[c] atrazine = 0.011 mg/kg
[d] endosulfan I = 0.065 mg/kg
[e] fipronil = 0.021 mg/kg
[f] gamma chlordane = 0.12 mg/kg
[g] 2,4-D = 0.45 mg/kg
[h] dicamba = 0.2 mg/kg

Table A2: Summary of chemical analysis of mixed waste organic outputs from Facility B

Chemical group	CAS Number	Chemical	No. of samples	No. Detects (% detects)	Average[1]	Minimum	Maximum	Median[1]	95th percentile[1]
Metals (mg/kg)	7429-90-5	Aluminium	64	64 (100)	6700	4400	10000	6700	8700
	7440-36-0	Antimony	64	4 (6)	4.7	<3.1	7.7	3.95	7.2
	7440-38-2	Arsenic	64	64 (100)	7.0	4.4	10	6.4	10
	7440-39-3	Barium	64	64 (100)	130	84	620	120	210
	7440-41-7	Beryllium	64	57 (89)	0.22	<0.11	0.38	0.21	0.34
	7440-42-8	Boron	64	40 (63)	18	<11	36	17	23
	7440-43-9	Cadmium	64	58 (91)	1.8	<0.51	15	1.20	4.6
	7440-47-3	Chromium	64	64 (100)	36	17	440	27	60
	7440-48-4	Cobalt	64	64 (100)	4.3	2.9	7	4.3	5.8
	7440-50-8	Copper	64	64 (100)	150	63	320	160	210
	7439-89-6	Iron	64	64 (100)	13000	7400	26000	12000	19000
	7439-92-1	Lead	64	64 (100)	150	42	1300	130	210
	7439-93-2	Lithium	64	57 (89)	2.6	<2.1	3.1	2.6	3
	7439-96-5	Manganese	64	64 (100)	320	200	830	320	450
	7439-97-6	Mercury	64	64 (100)	0.30	0.019	1.3	0.24	0.91
	7439-98-7	Molybdenum	64	28 (44)	8.6	<2.0	110	2.55	38
	7440-02-0	Nickel	64	64 (100)	24	12	42	24	32
	7782-49-2	Selenium	64	0 (0)		<3.1	<3.5		
	7440-22-4	Silver	64	29 (45)	1.1	<0.51	2.2	0.99	1.8
	7440-24-6	Strontium	64	64 (100)	81	54	190	78	100
	7704-34-9	Sulfur	64	64 (100)	3600	2600	8400	3500	4400
	7440-28-0	Thallium	64	0 (0)		< 1.0	<1.2		
	7440-31-5	Tin	64	64 (100)	50	8.5	1800	21	44
	7440-32-6	Titanium	64	64 (100)	63	34	220	59	82
	7440-62-2	Vanadium	64	64 (100)	12	7.0	19	12	17
	7440-66-6	Zinc	64	64 (100)	490	280	720	485	700
Major cations (g/kg)	7440-70-2	Calcium	64	64 (100)	29	17	42	30	37
	7439-95-4	Magnesium	64	64 (100)	2.7	1.9	4.5	2.6	3.6

Chemical group	CAS Number	Chemical	No. of samples	No. Detects (% detects)	Average[1]	Minimum	Maximum	Median[1]	95th percentile[1]
	7440-09-7	Potassium	64	64 (100)	7.8	5.1	14	7.4	13
	7440-23-5	Sodium	64	64 (100)	5.3	3.5	7.8	5.3	7.6
PAHs (mg/kg)	83-32-9	Acenaphthene	64	1 (2)	1.0	<0.13	1.0		
	208-96-8	Acenaphthylene	64	0 (0)		<0.13	<0.21		
	120-12-7	Anthracene	64	0 (0)		<0.13	<0.21		
	56-55-3	Benzo (a) anthracene	64	0 (0)		<0.13	<0.21		
	50-32-8	Benzo (a) pyrene	64	0 (0)		<0.13	<0.21		
	205-99-2	Benzo (b) fluoranthene	64	0 (0)		<0.13	<0.21		
	191-24-2	Benzo (ghi) perylene	64	0 (0)		<0.13	<0.21		
	207-08-9	Benzo (k) fluoranthene	64	0 (0)		<0.13	<0.21		
	218-01-9	Chrysene	64	0 (0)		<0.13	<0.21		
	53-70-3	Dibenzo (ah) anthracene	64	0 (0)		<0.13	<0.21		
	206-44-0	Fluoranthene	64	11 (17)	0.35	<0.13	1.2	0.2	0.89
	86-73-7	Fluorene	64	1 (2)	0.47	<0.13	0.47		
	193-39-5	Indeno (123cd) pyrene	64	0 (0)		<0.13	<0.21		
	91-20-3	Naphthalene	64	49 (77)	0.87	<0.13	2.8	0.68	2.0
	85-01-8	Phenanthrene	64	48 (75)	0.36	<0.14	1.3	0.33	0.52
	129-00-0	Pyrene	64	18 (28)	0.34	<0.13	1.1	0.295	0.58
Phenols (mg/kg)	58-90-2	2,3,4,6-Tetrachlorophenol	64	0 (0)		<0.38	<0.64		
	95-95-4	2,4,5-Trichlorophenol	64	0 (0)		<0.64	<1.1		
	88-06-2	2,4,6-Trichlorophenol	64	0 (0)		<0.26	<0.43		
	120-83-2	2,4-Dichlorophenol	64	0 (0)		<1.3	<2.1		
	105-67-9	2,4-Dimethylphenol	64	0 (0)		<3.2	<5.3		
	51-28-5	2,4-Dinitrophenol	64	0 (0)		<3.8	<6.4		
	121-14-2	2,4-Dinitrotoluene	64	0 (0)		<0.26	<0.43		
	87-65-0	2,6-Dichlorophenol	64	0 (0)		<0.26	<0.43		
	95-57-8	2-Chlorophenol	64	0 (0)		<0.38	<0.64		
	534-52-1	2-Methyl-4,6-dinitrophenol	64	0 (0)		<1.9	<3.2		
	95-48-7	2-Methylphenol	64	0 (0)		<0.64	<1.1		

Chemical group	CAS Number	Chemical	No. of samples	No. Detects (% detects)	Average[1]	Minimum	Maximum	Median[1]	95th percentile[1]
	88-75-5	2-Nitrophenol	64	0 (0)		<0.38	<0.64		
	108-39-4 and 106-44-5	3+4-Methylphenol	64	63 (98)	21	<0.78	71	14	50
	59-50-7	4-Chloro-3-methylphenol	64	0 (0)		<0.64	<1.1		
	100-02-7	4-Nitrophenol	64	0 (0)		<2.6	<4.3		
	87-86-5	Pentachlorophenol	64	0 (0)		<0.64	<1.1		
	108-95-2	Phenol	64	60 (94)	28	<0.42	98	26	57
Phthalates (mg/kg)	85-68-7	Benzyl butyl phthalate	20	1 (5)	2.9	<0.29	<3.7[a]		
	103-23-1	Bis-2-ethylhexyl adipate	17	15 (88)	9.5	<2.3	20	8.7	15
	117-81-7	Bis-2-ethylhexyl phthalate	64	64 (100)	70	10	180	59	130
	84-74-2	Dibutyl phthalate	64	28 (44)	6.3	<2.6	10	6.05	9.3
	84-66-2	Diethyl phthalate	20	3 (15)	2.7	<0.29	4.3	2.2	4.1
	131-11-3	Dimethyl phthalate	20	2 (10)	0.97	<0.29	1.5		
	117-84-0	Di-n-octyl phthalate	20	0 (0)		<0.29	<3.7		
Chlorobenzenes (mg/kg)	634-66-2	1,2,3,4-Tetrachlorobenzene	64	0 (0)		<0.38	<0.64		
	95-94-3	1,2,4,5-Tetrachlorobenzene	64	0 (0)		<0.26	<0.43		
	120-82-1	1,2,4-Trichlorobenzene	64	0 (0)		<0.38	<0.64		
	95-50-1	1,2-Dichlorobenzene	64	0 (0)		<0.38	<0.64		
	106-46-7	1,4-Dichlorobenzene	64	0 (0)		<0.38	<0.64		
	118-74-1	Hexachlorobenzene	58	0 (0)		<0.06	0.33		
	608-93-5	Pentachlorobenzene	64	0 (0)		<0.13	<0.21		
Nitrobenzenes (mg/kg)	98-95-3	Nitrobenzene	64	0 (0)		<0.13	<0.21		
	82-68-8	Pentachloronitrobenzene	64	0 (0)		<0.26	<0.43		
Pesticides (mg/kg)	309-00-2	Aldrin	58	0 (0)		<0.02	<0.33		
	584-79-2	Allethrin	22	0 (0)		<0.07	<1.1		
	319-84-6	alpha-BHC	58	0 (0)		<0.02	<0.33		
	5103-71-9	alpha-Chlordane	58	0 (0)		<0.02	<0.33		
	834-12-8	Ametryn	22	0 (0)		<0.14	<2.1		

Chemical group	CAS Number	Chemical	No. of samples	No. Detects (% detects)	Average[1]	Minimum	Maximum	Median[1]	95th percentile[1]
	1610-17-9	Atraton	22	0 (0)		<0.35	<5.3		
	1912-24-9	Atrazine	39	2 (5)	0.10	<0.008	0.11		
	131860-33-8	Azoxystrobin	22	0 (0)		<0.004	<0.008		
	319-85-7	beta-BHC	58	0 (0)		<0.02	<0.33		
	92880-79-0	Bifenthrin	22	7 (32)	0.38	<0.07	0.53	0.35	0.51
	28434-01-7	Bioresmethrin	22	0 (0)		<0.07	<1.1		
	56073-10-0	Brodifacoum	24	0 (0)		<0.01	<0.10		
	786-19-6	Carbophenothion	22	0 (0)		<0.07	<1.1		
	5234-68-4	Carboxin	22	0 (0)		<0.004	<0.008		
	2921-88-2	Chlorpyrifos	26	0 (0)		<0.07	<0.18		
	61949-76-6	cis-Permethrin	22	0 (0)		<0.07	<1.1		
	7700-17-6	Crotoxyphos	22	0 (0)		<0.07	<1.1		
	68359-37-5	Cyfluthrin	22	0 (0)		<0.17	<2.6		
	52315-07-8	Cypermethrin	22	0 (0)		<0.17	<2.6		
	319-86-8	delta-BHC	58	0 (0)		<0.02	<0.33		
	52918-63-5	Deltamethrin	22	0 (0)		<0.17	<2.6		
	333-41-5	Diazinon	8	0 (0)		<0.07	<0.33		
	1085-98-9	Dichlofluanid	24	0 (0)		<0.01	<0.04		
	62-73-7	Dichlorvos	22	0 (0)		<0.07	<1.1		
	60-57-1	Dieldrin	58	0 (0)		<0.02	<0.33		
	119446-68-3	Difenoconazole	22	0 (0)		<0.01	<0.02		
	60-51-5	Dimethoate	39	0 (0)		<0.01	<1.1		
	121124-29-6	Emamectin B1a	22	0 (0)		<0.006	<0.01		
	121424-52-0	Emamectin B1b	22	0 (0)		<0.006	<0.01		
	155569-91-8	Emamectin Benzoate	2	0 (0)		<0.10	<0.10		
	959-98-8	Endosulfan I	58	0 (0)		<0.02	<0.80		
	33213-65-9	Endosulfan II	58	0 (0)		<0.02	<0.80		
	1031-07-8	Endosulfan sulfate	58	0 (0)		<0.01	<0.80		
	72-20-8	Endrin	58	0 (0)		<0.01	<0.80		
	7421-93-4	Endrin aldehyde	26	0 (0)		<0.38	<0.56		
	53494-70-5	Endrin ketone	38	0 (0)		<0.26	<0.38		

Chemical group	CAS Number	Chemical	No. of samples	No. Detects (% detects)	Average[1]	Minimum	Maximum	Median[1]	95th percentile[1]
	563-12-2	Ethion	22	0 (0)		<0.07	<1.1		
	56-38-2	Ethyl parathion	22	0 (0)		<0.17	<2.6		
	22224-92-6	Fenamiphos	22	0 (0)		<0.42	<6.4		
	122-14-5	Fenitrothion	22	0 (0)		<0.07	<1.1		
	55-38-9	Fenthion	22	0 (0)		<0.07	<1.1		
	51630-58-1	Fenvalerate	22	0 (0)		<0.17	<2.6		
	120068-37-3	Fipronil	22	2 (9)	0.022	<0.01	<0.03[b]		
	79241-46-6	Fluazifop-p-butyl	22	0 (0)		<0.006	<0.01		
	131341-86-1	Fludioxonil	22	0 (0)		<0.06	<0.11		
	136426-54-5	Fluquinconazole	22	0 (0)		<0.02	<0.032		
	58-89-9	gamma-BHC	59	0 (0)		<0.02	<0.33		
	5103-74-2	gamma-chlordane	16	0 (0)		<0.02	<0.33		
	76-44-8	Heptachlor	58	0 (0)		<0.02	<0.33		
	66240-71-9	Heptachlor epoxide	58	0 (0)		<0.02	<0.33		
	51235-04-2	Hexazinone	22	0 (0)		<0.14	<2.1		
	138261-41-3	Imidacloprid	22	0 (0)		<0.02	<0.04		
	144171-61-9	Indoxacarb	22	0 (0)		<0.02	<0.04		
	465-73-6	Isodrin	64	0 (0)		<0.26	<0.43		
	91465-08-6	l-Cyhalothrin	22	0 (0)		<0.07	<1.1		
	121-75-5	Malathion	22	0 (0)		<0.7	<1.1		
	57837-19-1	Metalaxyl	22	1 (5)	0.006	<0.006	<0.008[c]		
	950-37-8	Methidation	22	0 (0)		<0.07	<1.1		
	72-43-5	Methoxychlor	69	0 (0)		<0.02	<1.1		
	86-50-0	Methyl azinphos	22	0 (0)		<0.07	<1.1		
	5598-13-0	Methyl chlorpyrifos	22	0 (0)		<0.07	<1.1		
	298-00-0	Methyl parathion	22	0 (0)		<0.17	<2.6		
	7786-34-7	Mevinphos	22	0 (0)		<0.07	<1.1		
	42874-03-3	Oxyfluorfen	20	0 (0)		<0.42	<2.1		
	298-02-2	Phorate	22	0 (0)		<0.07	<1.1		
	72-54-8	pp-DDD	58	0 (0)		<0.02	<0.33		
	72-55-9	pp-DDE	58	0 (0)		<0.02	<0.33		

Chemical group	CAS Number	Chemical	No. of samples	No. Detects (% detects)	Average[1]	Minimum	Maximum	Median[1]	95th percentile[1]
	50-29-3	pp-DDT	58	0 (0)		<0.02	<0.33		
	41198-08-7	Profenofos	22	0 (0)		<0.17	<2.6		
	1610-18-0	Prometon	22	0 (0)		<0.14	<2.1		
	7287-19-6	Prometryn	57	2 (4)	0.057	<0.03	<6.4[d]		
	2312-35-8	Propargite	38	0 (0)		<0.009	<9.4		
	139-40-2	Propazine	22	0 (0)		<0.14	<2.1		
	31218-83-4	Propetamphos	22	0 (0)		<0.07	<1.1		
	122-34-9	Simazine	39	0 (0)		<0.02	<3.2		
	1014-70-6	Simetryn	22	0 (0)		<0.14	<2.1		
	35400-43-2	Sulprofos	22	0 (0)		<0.07	<1.1		
	107534-96-3	Tebuconazole	22	0 (0)		<0.42	<4.0		
	34014-18-1	Tebuthiuron	22	0 (0)		<0.14	<2.1		
	5915-41-3	Terbuthylazine	22	0 (0)		<0.14	<2.1		
	886-50-0	Terbutryn	22	0 (0)		<0.14	<2.1		
	22248-79-9	Tetrachlorvinphos	22	0 (0)		<0.17	<2.6		
	148-79-8	Thiabendazole	22	16 (73)	0.018	<0.009	0.04	0.014	0.036
	153719-23-4	Thiamethoxam	22	0 (0)		<0.007	<0.01		
	59669-26-0	Thiodicarb	22	0 (0)		<0.008	<0.02		
	61949-77-7	trans-Permethrin	22	2 (9)	0.35	<0.07	<1.1[e]		
Herbicides (mg/kg)	93-76-5	2,4,5-T	46	1 (2)	0.45	<0.09	0.45		
	93-72-1	2,4,5-TP	46	0 (0)		<0.03	<0.14		
	94-75-7	2,4-D	46	1 (2)	0.74	<0.05	0.74		
	94-82-6	2,4-DB	46	0 (0)		<0.03	<0.14		
	1918-00-9	Dicamba	46	22 (48)	0.096	<0.04	0.19	0.093	0.16
	88-85-7	Dinoseb	46	0 (0)		<0.64	<1.1		
	1071-83-6	Glyphosate	6	0 (0)		<1.5	<2.1		
	94-74-6	MCPA	45	29 (64)	0.46	<0.06	1.6	0.39	1.3
	93-65-2	MCPP	25	16 (64)	0.077	<0.01	0.14	0.096	0.12
	1918-02-1	Picloram	42	0 (0)		<0.08	<0.34		
	55335-06-3	Triclopyr	46	0 (0)		<0.09	<0.41		

Chemical group	CAS Number	Chemical	No. of samples	No. Detects (% detects)	Average[1]	Minimum	Maximum	Median[1]	95th percentile[1]
PCBS (mg/kg)	12674-11-2	Aroclor 1016 (screen)	55	0 (0)		<0.51	<0.77		
	11104-28-2	Aroclor 1221 (screen)	38	0 (0)		<0.51	<0.77		
	11141-16-5	Aroclor 1232 (screen)	55	0 (0)		<0.51	<0.77		
	53469-21-9	Aroclor 1242 (screen)	55	0 (0)		<0.51	<0.77		
	12672-29-6	Aroclor 1248 (screen)	55	0 (0)		<0.51	<0.77		
	11097-69-1	Aroclor 1254 (screen)	55	0 (0)		<0.51	<0.77		
	11096-82-5	Aroclor 1260 (screen)	55	0 (0)		<0.51	<0.77		
PCBs (mg/kg)	12674-11-2	Aroclor 1016	13	0 (0)		<0.01	<0.71		
	11104-28-2	Aroclor 1221	13	0 (0)		<0.01	<0.71		
	11141-16-5	Aroclor 1232	13	0 (0)		<0.01	<0.71		
	53469-21-9	Aroclor 1242	13	0 (0)		<0.01	<0.71		
	12672-29-6	Aroclor 1248	13	0 (0)		<0.01	<0.71		
	11097-69-1	Aroclor 1254	13	0 (0)		<0.01	<0.71		
	11096-82-5	Aroclor 1260	13	0 (0)		<0.01	<0.71		
Alkylphenols (mg/kg)	1806-26-4	4-octylphenol	12	5 (42)	0.14	<0.08	0.15	0.14	0.15
	84852-15-3	4-nonylphenol	12	12 (100)	2.7	0.82	3.7	2.7	3.7
	140-66-9	4-tert-octylphenol	12	0 (0)		<0.08	<0.12		
	80-05-7	Bisphenol A	12	12 (100)	34	4.0	100	22	81
Organotins (µg/kg)	78763-54-9	Monobutyl Tin	6	6 (100)	7.1	3.4	14	5.4	13
	1191-48-6	Dibutyl Tin	6	6 (100)	7.7	2.7	15	6.6	13
	688-73-3	Tributyl Tin	6	1 (17)	1.1	<0.5	1.1		
PBDEs (µg/kg)	N/A	Total PBDEs	6	6 (100)	340	96	970	255	820
	N/A	Tri-BDE	6	6 (100)	1.2	0.59	2.3	0.98	2.1
	N/A	Tetra-BDE	6	6 (100)	20	11	32	19	32
	N/A	Penta-BDE	6	6 (100)	31	13	59	28	55
	N/A	Hexa-BDE	6	6 (100)	7.7	3.3	13	7.9	12
	N/A	Hepta-BDE	6	6 (100)	8.5	3.3	14	8.4	14

Chemical group	CAS Number	Chemical	No. of samples	No. Detects (% detects)	Average[1]	Minimum	Maximum	Median[1]	95th percentile[1]
	N/A	Octa-BDE	6	6 (100)	8.9	2.7	17	9.0	16
	N/A	Nona-BDE	6	6 (100)	25	6.1	67	20	58
	N/A	Deca-BDE	6	6 (100)	240	54	810	140	660
Perfluorinated compounds (µg/kg)	1763-23-1	PFOA	1	0 (0)		<1.0	<1.0		
	335-67-1	PFOS	1	0 (0)		<3.0	<3.0		
Nutrients (mg/kg)	N/A	TKN	13	13 (100)	19000	8800	26000	20000	24000
	7723-14-0	Phosphorus	62	62 (100)	4800	3500	7500	4700	6200
Other	N/A	Asbestos (g/kg)	6	0 (0)		<0.1	<0.1		
	N/A	Conductivity (dS/m)	22	22 (100)	8.5	5.2	14	7.9	14
	N/A	pH (water)	22	22 (100)	6.9	5.7	8.7	6.8	8.1
	N/A	TOC (% Carbon)	17	17 (100)	33	19	45	31	44

[1] only concentrations that were above the limit of quantification were used to calculate the average, median and 95th percentile concentrations

Maximum measured concentration of:

[a] benzyl butyl phthalate = 2.9 mg/kg

[b] fipronil = 0.022 mg/kg

[c] metalaxyl = 0.006 mg/kg

[d] prometryn = 0.089

[e] trans-permethrin = 0.5 mg/kg

Table A3: Summary of chemical analysis of column leachates generated from mixed waste organic outputs from Facility A

Chemical group	CAS Number	Chemical	F1 Fraction		F2 Fraction		F3 Fraction		F4 Fraction	
			Min	Max	Min	Max	Min	Max	Min	Max
Metals (mg/L)	7429-90-5	Aluminium	4.4	13	1.3	1.7	0.29	0.43	0.10	0.14
	7440-36-0	Antimony	0.05	0.05	0.01	0.01	<0.01	<0.01	<0.01	<0.01
	7440-38-2	Arsenic	0.05	0.07	<0.03	0.04	<0.03	<0.03	<0.03	<0.03
	7440-39-3	Barium	0.10	0.21	0.02	0.03	<0.02	<0.02	<0.02	<0.02
	7440-41-7	Beryllium	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	7440-42-8	Boron	1.7	1.9	0.5	0.6	0.1	0.2	<0.1	<0.1
	7440-43-9	Cadmium	<0.01	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	7440-47-3	Chromium	0.3	0.47	0.06	0.11	0.02	0.02	<0.01	<0.01
	7440-48-4	Cobalt	0.09	0.21	0.03	0.04	<0.01	0.01	<0.01	<0.01
	7440-50-8	Copper	1.4	7.2	0.26	1.2	0.05	0.18	0.01	0.05
	7439-89-6	Iron	11	12	2.1	3.2	0.71	0.85	0.58	0.58
	7439-92-1	Lead	0.28	0.4	0.06	0.13	<0.02	0.03	<0.02	<0.02
	7439-93-2	Lithium	0.06	0.08	<0.02	0.02	<0.02	<0.02	<0.02	<0.02
	7439-96-5	Manganese	1.6	7.0	0.39	1.3	0.08	0.69	0.13	0.57
	7439-97-6	Mercury (ug/L)	0.43	2.0	0.24	0.57	0.11	0.14	0.05	0.06
	7439-98-7	Molybdenum	0.11	0.15	0.05	0.04	<0.01	0.01	<0.01	<0.01
	7440-02-0	Nickel	0.84	2.6	0.25	0.61	0.04	0.2	<0.02	0.07
	7782-49-2	Selenium	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
	7440-21-3	Silicon	5.8	6.1	3.4	5.9	3.3	4.6	3.0	3.2
	7440-22-4	Silver	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
	7440-24-6	Strontium	0.95	2.6	0.19	0.78	0.04	0.59	0.08	0.48
	7704-34-9	Sulfur	270	300	47	49	4.5	7.7	1.2	1.4
	7440-28-0	Thallium	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
	7440-31-5	Tin	0.06	0.08	<0.02	0.03	<0.02	<0.02	<0.02	<0.02
	7440-32-6	Titanium	0.15	0.3	0.02	0.04	<0.01	<0.01	<0.01	<0.01
	7440-62-2	Vanadium	0.03	0.03	<0.01	0.02	<0.01	<0.01	<0.01	<0.01
	7440-66-6	Zinc	4.2	13	1.1	2.8	0.15	0.95	0.07	0.31

Chemical group	CAS Number	Chemical	F1 Fraction		F2 Fraction		F3 Fraction		F4 Fraction	
			Min	Max	Min	Max	Min	Max	Min	Max
Major cations (mg/L)	7440-70-2	Calcium	420	920	76	180	18	110	36	98
	7439-95-4	Magnesium	73	130	13	22	2.4	10	5.3	5.7
	7440-09-7	Potassium	530	780	130	150	24	43	3.9	4.3
	7440-23-5	Sodium	810	870	150	170	15	29	1.7	1.7
Major anions (mg/L)	N/A	Chloride	760	900	81	120	1.4	10	<0.6	<0.6
	N/A	Sulfate	760	790	110	140	11	21	2.4	4.9
	N/A	Sulfide	<0.1	0.2	nm	nm	nm	nm	nm	nm
PAHs (mg/L)	83-32-9	Acenaphthene	<0.004	<0.008	<0.004	<0.008	<0.004	<0.008	<0.004	<0.004
	208-96-8	Acenaphthylene	<0.004	<0.008	<0.004	<0.008	<0.004	<0.008	<0.004	<0.004
	120-12-7	Anthracene	<0.004	<0.008	<0.004	<0.008	<0.004	<0.008	<0.004	<0.004
	56-55-3	Benzo (a) anthracene	<0.004	<0.008	<0.004	<0.008	<0.004	<0.008	<0.004	<0.004
	50-32-8	Benzo (a) pyrene	<0.002	<0.004	<0.002	<0.004	<0.002	<0.004	<0.002	<0.002
	205-99-2	Benzo (b) fluoranthene	<0.002	<0.004	<0.002	<0.004	<0.002	<0.004	<0.002	<0.002
	191-24-2	Benzo (ghi) perylene	<0.002	<0.004	<0.002	<0.004	<0.002	<0.004	<0.002	<0.002
	207-08-9	Benzo (k) fluoranthene	<0.002	<0.004	<0.002	<0.004	<0.002	<0.004	<0.002	<0.002
	218-01-9	Chrysene	<0.002	<0.004	<0.002	<0.004	<0.002	<0.004	<0.002	<0.002
	53-70-3	Dibenzo (ah) anthracene	<0.002	<0.004	<0.002	<0.004	<0.002	<0.004	<0.002	<0.002
	206-44-0	Fluoranthene	<0.01	<0.02	<0.01	<0.02	<0.01	<0.02	<0.01	<0.01
	86-73-7	Fluorene	<0.004	<0.008	<0.004	<0.008	<0.004	<0.008	<0.004	<0.004
	193-39-5	Indeno (123cd) pyrene	<0.002	<0.004	<0.002	<0.004	<0.002	<0.004	<0.002	<0.002
	91-20-3	Naphthalene	<0.004	<0.008	<0.004	<0.008	<0.004	<0.008	<0.004	<0.004
	85-01-8	Phenanthrene	<0.004	<0.008	<0.004	<0.008	<0.004	<0.008	<0.004	<0.004
	129-00-0	Pyrene	<0.002	<0.004	<0.002	<0.004	<0.002	<0.004	<0.002	<0.002
Phenols (mg/L)	58-90-2	2,3,4,6-Tetrachlorophenol	<0.02	<0.04	<0.02	<0.04	<0.02	<0.04	<0.02	<0.02
	95-95-4	2,4,5-Thrichlorophenol	<0.01	<0.02	<0.01	<0.02	<0.01	<0.02	<0.01	<0.01
	88-06-2	2,4,6-Thrichlorophenol	<0.01	<0.02	<0.01	<0.02	<0.01	<0.02	<0.01	<0.01
	120-83-2	2,4-Dichlorophenol	<0.01	<0.02	<0.01	<0.02	<0.01	<0.02	<0.01	<0.01

Chemical group	CAS Number	Chemical	F1 Fraction		F2 Fraction		F3 Fraction		F4 Fraction	
			Min	Max	Min	Max	Min	Max	Min	Max
	105-67-9	2,4-Dimethylphenol	<0.01	<0.02	<0.01	<0.02	<0.01	<0.02	<0.01	<0.01
	51-28-5	2,4-Dinitrophenol	<0.4	<0.8	<0.4	<0.8	<0.4	<0.8	<0.4	<0.4
	121-14-2	2,4-Dinitrotoluene	<0.02	<0.04	<0.02	<0.04	<0.02	<0.04	<0.02	<0.02
	87-65-0	2,6-Dichlorophenol	<0.01	<0.02	<0.01	<0.02	<0.01	<0.02	<0.01	<0.01
	95-57-8	2-Chlorophenol	<0.006	<0.012	<0.006	<0.012	<0.006	<0.012	<0.006	<0.012
	534-52-1	2-Methyl-4,6-dinitrophenol	<0.06	<0.12	<0.06	<0.12	<0.06	<0.12	<0.06	<0.12
	95-48-7	2-Methylphenol	<0.01	<0.02	<0.01	<0.02	<0.01	<0.02	<0.01	<0.01
	88-75-5	2-Nitrophenol	<0.01	<0.02	<0.01	<0.02	<0.01	<0.02	<0.01	<0.01
	108-39-4 and 106-44-5	3+4-Methylphenol	0.044	0.11	0.026	0.041	<0.02	<0.01	<0.01	<0.01
	59-50-7	4-Chloro-3-methylphenol	<0.01	<0.02	<0.01	<0.02	<0.01	<0.02	<0.01	<0.01
	100-02-7	4-Nitrophenol	<0.06	<0.12	<0.06	<0.12	<0.06	<0.12	<0.06	<0.12
	87-86-5	Pentachlorophenol	<0.01	<0.02	<0.01	<0.02	<0.01	<0.02	<0.01	<0.01
	108-95-2	Phenol	1.7	2.3	0.65	1.2	<0.012	0.25	<0.012	<0.012
Phthalates (mg/L)	103-23-1	Bis-2-ethylhexyl adipate	<0.24	<0.48	<0.24	<0.48	<0.24	<0.48	<0.24	<0.24
	117-81-7	Bis-2-ethylhexyl phthalate	<0.12	<0.24	<0.12	<0.24	<0.12	<0.24	<0.12	<0.12
	84-74-2	Dibutyl phthalate	<0.04	<0.08	<0.04	<0.08	<0.04	<0.08	<0.04	<0.04
Chlorobenzenes (mg/L)	634-66-2	1,2,3,4-Tetrachlorobenzene	<0.002	<0.004	<0.002	<0.004	<0.002	<0.004	<0.002	<0.004
	95-94-3	1,2,4,5-Tetrachlorobenzene	<0.01	<0.02	<0.01	<0.02	<0.01	<0.02	<0.01	<0.01
	120-82-1	1,2,4-Trichlorobenzene	<0.01	<0.02	<0.01	<0.02	<0.01	<0.02	<0.01	<0.01
	95-50-1	1,2-Dichlorobenzene	<0.006	<0.012	<0.006	<0.012	<0.006	<0.012	<0.006	<0.006
	106-46-7	1,4-Dichlorobenzene	<0.006	<0.012	<0.006	<0.012	<0.006	<0.012	<0.006	<0.006
	118-74-1	Hexachlorobenzene	<0.004	<0.008	<0.004	<0.008	<0.004	<0.008	<0.004	<0.008
	608-93-5	Pentachlorobenzene	<0.01	<0.02	<0.01	<0.02	<0.01	<0.02	<0.01	<0.01
Nitrobenzenes (mg/L)	98-95-3	Nitrobenzene	<0.01	<0.02	<0.01	<0.02	<0.01	<0.02	<0.01	<0.01
	82-68-8	Pentachloronitrobenzene	<0.01	<0.02	<0.01	<0.02	<0.01	<0.02	<0.01	<0.01
Pesticides (mg/L)	309-00-2	Aldrin	<0.01	<0.02	<0.01	<0.02	<0.01	<0.02	<0.01	<0.01

Chemical group	CAS Number	Chemical	F1 Fraction		F2 Fraction		F3 Fraction		F4 Fraction	
			Min	Max	Min	Max	Min	Max	Min	Max
	319-84-6	alpha-BHC	<0.01	<0.02	<0.01	<0.02	<0.01	<0.02	<0.01	<0.01
	5103-71-9	alpha-Chlordane	<0.01	<0.02	<0.01	<0.02	<0.01	<0.02	<0.01	<0.01
	319-85-7	beta-BHC	<0.01	<0.02	<0.01	<0.02	<0.01	<0.02	<0.01	<0.01
	319-86-8	delta-BHC	<0.01	<0.02	<0.01	<0.02	<0.01	<0.02	<0.01	<0.01
	60-57-1	Dieldrin	<0.006	<0.012	<0.006	<0.012	<0.006	<0.012	<0.006	<0.006
	959-98-8	Endosulfan I	<0.01	<0.02	<0.01	<0.02	<0.01	<0.02	<0.01	<0.01
	33213-65-9	Endosulfan II	<0.01	<0.02	<0.01	<0.02	<0.01	<0.02	<0.01	<0.01
	1031-07-8	Endosulfan sulfate	<0.01	<0.02	<0.01	<0.02	<0.01	<0.02	<0.01	<0.01
	72-20-8	Endrin	<0.01	<0.02	<0.01	<0.02	<0.01	<0.02	<0.01	<0.01
	7421-93-4	Endrin aldehyde	<0.07	<0.14	<0.07	<0.14	<0.07	<0.14	<0.07	<0.07
	53494-70-5	Endrin ketone	<0.01	<0.02	<0.01	<0.02	<0.01	<0.02	<0.01	<0.01
	58-89-9	gamma-BHC	<0.01	<0.02	<0.01	<0.02	<0.01	<0.02	<0.01	<0.01
	5103-74-2	gamma-chlordane	<0.002	<0.004	<0.002	<0.004	<0.002	<0.004	<0.002	<0.002
	76-44-8	Heptachlor	<0.01	<0.02	<0.01	<0.02	<0.01	<0.02	<0.01	<0.01
	66240-71-9	Heptachlor epoxide	<0.01	<0.02	<0.01	<0.02	<0.01	<0.02	<0.01	<0.01
	465-73-6	Isodrin	<0.01	<0.02	<0.01	<0.02	<0.01	<0.02	<0.01	<0.01
	72-43-5	Methoxychlor	<0.006	<0.012	<0.006	<0.012	<0.006	<0.012	<0.006	<0.006
	72-54-8	pp-DDD	<0.006	<0.012	<0.006	<0.012	<0.006	<0.012	<0.006	<0.006
	72-55-9	pp-DDE	<0.006	<0.012	<0.006	<0.012	<0.006	<0.012	<0.006	<0.006
	50-29-3	pp-DDT	<0.006	<0.012	<0.006	<0.012	<0.006	<0.012	<0.006	<0.006
Herbicides (mg/L)	93-76-5	2,4,5-T	<0.001	<0.003	<0.001	<0.003	<0.001	<0.003	<0.001	<0.001
	93-72-1	2,4,5-TP	<0.001	<0.003	<0.001	<0.003	<0.001	<0.003	<0.001	<0.001
	94-75-7	2,4-D	<0.001	0.037	<0.001	0.022	<0.001	<0.003	<0.001	<0.001
	94-82-6	2,4-DB	<0.001	<0.003	<0.001	<0.003	<0.001	<0.003	<0.001	<0.001
	1918-00-9	Dicamba	0.011	0.012	<0.003	0.004	<0.001	<0.003	<0.001	<0.001
	15165-67-0	Dichloroprop	<0.001	<0.003	<0.001	<0.003	<0.001	<0.003	<0.001	<0.001
	88-85-7	Dinoseb	<0.04	<0.08	<0.04	<0.08	<0.04	<0.08	<0.04	<0.04
	94-74-6	MCPA	0.047	0.063	0.024	0.038	<0.003	0.011	<0.001	<0.001
	93-65-2	MCPP	<0.001	0.01	<0.001	0.004	<0.001	<0.003	<0.001	<0.001

Chemical group	CAS Number	Chemical	F1 Fraction		F2 Fraction		F3 Fraction		F4 Fraction	
			Min	Max	Min	Max	Min	Max	Min	Max
	1918-02-1	Picloram	<0.001	<0.003	<0.001	<0.003	<0.001	<0.003	<0.001	<0.001
	55335-06-3	Triclopyr	0.003	0.009	0.002	0.005	<0.001	<0.003	<0.001	<0.001
PCBs (mg/L)	12674-11-2	Aroclor 1016 (screen)	<0.008	<0.016	<0.008	<0.016	<0.008	<0.016	<0.008	<0.008
	11104-28-2	Aroclor 1221 (screen)	<0.008	<0.016	<0.008	<0.016	<0.008	<0.016	<0.008	<0.008
	11141-16-5	Aroclor 1232 (screen)	<0.008	<0.016	<0.008	<0.016	<0.008	<0.016	<0.008	<0.008
	53469-21-9	Aroclor 1242 (screen)	<0.008	<0.016	<0.008	<0.016	<0.008	<0.016	<0.008	<0.008
	12672-29-6	Aroclor 1248 (screen)	<0.008	<0.016	<0.008	<0.016	<0.008	<0.016	<0.008	<0.008
	11097-69-1	Aroclor 1254 (screen)	<0.008	<0.016	<0.008	<0.016	<0.008	<0.016	<0.008	<0.008
	11096-82-5	Aroclor 1260 (screen)	<0.008	<0.016	<0.008	<0.016	<0.008	<0.016	<0.008	<0.008
Nutrients (mg/L)	7664-41-7	Ammonia	260	390	49	120	7.3	15	<0.01	0.01
	N/A	Free Reactive Phosphorus	1.7	2.5	0.29	2.3	0.25	1.5	0.6	1.5
	N/A	NOx-N	<0.02	22	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
	7723-14-0	Phosphorus	10	15	2.4	4.2	0.7	2.0	0.95	2.0
Other	N/A	Conductivity (µS/cm)	10000	10000	2400	2400	870	870	500	500
	N/A	Dissolved Organic Carbon (mg/L)	6200	6200	nm	nm	nm	nm	nm	nm
	N/A	pH	6.8	6.8	7.2	7.2	7.3	7.3	7.9	7.9

nm, not measured

Table A4: Summary of chemical analysis of column leachates generated from mixed waste organic outputs from Facility B

Chemical group	CAS Number	Chemical	F1 Fraction		F2 Fraction		F3 Fraction		F4 Fraction	
			Min	Max	Min	Max	Min	Max	Min	Max
Metals (mg/L)	7429-90-5	Aluminium	2.7	16	2.7	3.2	1.6	2.6	0.33	0.57
	7440-36-0	Antimony	0.02	0.04	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	7440-38-2	Arsenic	0.07	0.11	0.04	0.05	<0.03	0.03	<0.03	<0.03
	7440-39-3	Barium	0.07	0.18	0.03	0.05	<0.02	0.02	<0.02	<0.02
	7440-41-7	Beryllium	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	7440-42-8	Boron	0.06	1.7	0.4	0.5	0.2	0.2	<0.1	<0.1
	7440-43-9	Cadmium	<0.01	0.04	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	7440-47-3	Chromium	0.07	0.18	0.03	0.04	0.01	0.01	<0.01	<0.01
	7440-48-4	Cobalt	0.03	0.08	0.02	0.02	<0.01	<0.01	<0.01	<0.01
	7440-50-8	Copper	1.1	1.6	0.22	0.91	0.09	0.22	0.01	0.03
	7439-89-6	Iron	8.4	23	6.0	6.4	2.8	3.4	0.71	2.4
	7439-92-1	Lead	0.1	0.23	0.05	0.28	0.02	0.08	<0.02	<0.02
	7439-93-2	Lithium	<0.02	0.08	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
	7439-96-5	Manganese	0.31	6.4	0.19	1.2	0.09	0.31	0.04	0.37
	7439-97-6	Mercury (ug/L)	0.11	1.1	0.24	0.66	0.2	0.22	0.07	0.08
	7439-98-7	Molybdenum	0.07	0.11	0.01	0.03	<0.01	0.02	<0.01	<0.01
	7440-02-0	Nickel	0.24	0.98	0.11	0.32	0.04	0.14	<0.02	0.04
	7782-49-2	Selenium	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
	7440-21-3	Silicon	4.8	9.0	3.9	5.7	3.2	6.4	2.3	4.1
	7440-22-4	Silver	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
	7440-24-6	Strontium	0.1	2.9	0.05	0.82	<0.03	0.33	<0.03	0.41
	7704-34-9	Sulfur	120	280	18	53	5.5	9.4	1.6	2.2
	7440-28-0	Thallium	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
	7440-31-5	Tin	0.04	0.08	<0.02	0.03	<0.02	<0.02	<0.02	<0.02
	7440-32-6	Titanium	0.06	0.49	0.05	0.06	0.02	0.05	<0.01	0.02
	7440-62-2	Vanadium	0.05	0.06	0.01	0.03	<0.01	0.01	<0.01	<0.01
	7440-66-6	Zinc	1.4	14	0.87	3.6	0.31	1.3	0.06	0.37

Chemical group	CAS Number	Chemical	F1 Fraction		F2 Fraction		F3 Fraction		F4 Fraction	
			Min	Max	Min	Max	Min	Max	Min	Max
Major cations (mg/L)	7440-70-2	Calcium	40	1200	19	240	9.2	66	8.3	85
	7439-95-4	Magnesium	15	190	5.1	29	2.6	5.7	3.3	7.3
	7440-09-7	Potassium	560	1200	160	170	37	69	29	13
	7440-23-5	Sodium	420	860	100	160	25	37	3.0	7.4
Major anions (mg/L)	N/A	Chloride	740	1100	43	140	0.8	8.0	<0.6	<0.6
	N/A	Sulfate	240	770	25	140	8.0	20	2.0	3.8
	N/A	Sulfide	<0.1	0.29	nm	nm	nm	nm	nm	nm
PAHs (mg/L)	83-32-9	Acenaphthene	<0.004	<0.008	<0.004	<0.008	<0.004	<0.008	<0.004	<0.004
	208-96-8	Acenaphthylene	<0.004	<0.008	<0.004	<0.008	<0.004	<0.008	<0.004	<0.004
	120-12-7	Anthracene	<0.004	<0.008	<0.004	<0.008	<0.004	<0.008	<0.004	<0.004
	56-55-3	Benzo (a) anthracene	<0.004	<0.008	<0.004	<0.008	<0.004	<0.008	<0.004	<0.004
	50-32-8	Benzo (a) pyrene	<0.002	<0.004	<0.002	<0.004	<0.002	<0.004	<0.002	<0.002
	205-99-2	Benzo (b) fluoranthene	<0.002	<0.004	<0.002	<0.004	<0.002	<0.004	<0.002	<0.002
	191-24-2	Benzo (ghi) perylene	<0.002	<0.004	<0.002	<0.004	<0.002	<0.004	<0.002	<0.002
	207-08-9	Benzo (k) fluoranthene	<0.002	<0.004	<0.002	<0.004	<0.002	<0.004	<0.002	<0.002
	218-01-9	Chrysene	<0.002	<0.004	<0.002	<0.004	<0.002	<0.004	<0.002	<0.002
	53-70-3	Dibenzo (ah) anthracene	<0.002	<0.004	<0.002	<0.004	<0.002	<0.004	<0.002	<0.002
	206-44-0	Fluoranthene	<0.01	<0.02	<0.01	<0.02	<0.01	<0.02	<0.01	<0.01
	86-73-7	Fluorene	<0.004	<0.008	<0.004	<0.008	<0.004	<0.008	<0.004	<0.004
	193-39-5	Indeno (123cd) pyrene	<0.002	<0.004	<0.002	<0.004	<0.002	<0.004	<0.002	<0.002
	91-20-3	Naphthalene	<0.004	<0.008	<0.004	<0.008	<0.004	<0.008	<0.004	<0.004
	85-01-8	Phenanthrene	<0.004	<0.008	<0.004	<0.008	<0.004	<0.008	<0.004	<0.004
	129-00-0	Pyrene	<0.002	<0.004	<0.002	<0.004	<0.002	<0.004	<0.002	<0.002
Phenols (mg/L)	58-90-2	2,3,4,6-Tetrachlorophenol	<0.02	<0.04	<0.02	<0.04	<0.02	<0.04	<0.02	<0.02
	95-95-4	2,4,5-Thrichlorophenol	<0.01	<0.02	<0.01	<0.02	<0.01	<0.02	<0.01	<0.01
	88-06-2	2,4,6-Thrichlorophenol	<0.01	<0.02	<0.01	<0.02	<0.01	<0.02	<0.01	<0.01
	120-83-2	2,4-Dichlorophenol	<0.01	<0.02	<0.01	<0.02	<0.01	<0.02	<0.01	<0.01

Chemical group	CAS Number	Chemical	F1 Fraction		F2 Fraction		F3 Fraction		F4 Fraction	
			Min	Max	Min	Max	Min	Max	Min	Max
	105-67-9	2,4-Dimethylphenol	<0.01	<0.02	<0.01	<0.02	<0.01	<0.02	<0.01	<0.01
	51-28-5	2,4-Dinitrophenol	<0.4	<0.8	<0.4	<0.8	<0.4	<0.8	<0.4	<0.4
	121-14-2	2,4-Dinitrotoluene	<0.02	<0.04	<0.02	<0.04	<0.02	<0.04	<0.02	<0.02
	87-65-0	2,6-Dichlorophenol	<0.01	<0.02	<0.01	<0.02	<0.01	<0.02	<0.01	<0.01
	95-57-8	2-Chlorophenol	<0.006	<0.012	<0.006	<0.012	<0.006	<0.012	<0.006	<0.012
	534-52-1	2-Methyl-4,6-dinitrophenol	<0.06	<0.12	<0.06	<0.12	<0.06	<0.12	<0.06	<0.12
	95-48-7	2-Methylphenol	<0.01	<0.02	<0.01	<0.02	<0.01	<0.02	<0.01	<0.01
	88-75-5	2-Nitrophenol	<0.01	<0.02	<0.01	<0.02	<0.01	<0.02	<0.01	<0.01
	108-39-4 and 106-44-5	3+4-Methylphenol	<0.02	0.4	<0.02	0.26	<0.04	0.15	<0.01	0.01
	59-50-7	4-Chloro-3-methylphenol	<0.01	<0.02	<0.01	<0.02	<0.01	<0.02	<0.01	<0.01
	100-02-7	4-Nitrophenol	<0.06	<0.12	<0.06	<0.12	<0.06	<0.12	<0.06	<0.12
	87-86-5	Pentachlorophenol	<0.01	<0.02	<0.01	<0.02	<0.01	<0.02	<0.01	<0.01
	108-95-2	Phenol	<0.012	1.1	<0.012	0.49	<0.012	0.19	<0.006	0.01
Phthalates (mg/L)	103-23-1	Bis-2-ethylhexyl adipate	<0.24	<0.48	<0.24	<0.48	<0.24	<0.48	<0.24	<0.24
	117-81-7	Bis-2-ethylhexyl phthalate	<0.12	<0.24	<0.12	<0.24	<0.12	<0.24	<0.12	<0.24
	84-74-2	Dibutyl phthalate	<0.04	<0.08	<0.04	<0.08	<0.04	<0.08	<0.04	<0.08
Chlorobenzenes (mg/L)	634-66-2	1,2,3,4-Tetrachlorobenzene	<0.002	<0.004	<0.002	<0.004	<0.002	<0.004	<0.002	<0.004
	95-94-3	1,2,4,5-Tetrachlorobenzene	<0.01	<0.02	<0.01	<0.02	<0.01	<0.02	<0.01	<0.01
	120-82-1	1,2,4-Trichlorobenzene	<0.01	<0.02	<0.01	<0.02	<0.01	<0.02	<0.01	<0.01
	95-50-1	1,2-Dichlorobenzene	<0.006	<0.012	<0.006	<0.012	<0.006	<0.012	<0.006	<0.006
	106-46-7	1,4-Dichlorobenzene	<0.006	<0.012	<0.006	<0.012	<0.006	<0.012	<0.006	<0.006
	118-74-1	Hexachlorobenzene	<0.004	<0.008	<0.004	<0.008	<0.004	<0.008	<0.004	<0.008
	608-93-5	Pentachlorobenzene	<0.01	<0.02	<0.01	<0.02	<0.01	<0.02	<0.01	<0.01
Nitrobenzenes (mg/L)	98-95-3	Nitrobenzene	<0.01	<0.02	<0.01	<0.02	<0.01	<0.02	<0.01	<0.01
	82-68-8	Pentachloronitrobenzene	<0.01	<0.02	<0.01	<0.02	<0.01	<0.02	<0.01	<0.01
Pesticides (mg/L)	309-00-2	Aldrin	<0.01	<0.02	<0.01	<0.02	<0.01	<0.02	<0.01	<0.01

Chemical group	CAS Number	Chemical	F1 Fraction		F2 Fraction		F3 Fraction		F4 Fraction	
			Min	Max	Min	Max	Min	Max	Min	Max
	319-84-6	alpha-BHC	<0.01	<0.02	<0.01	<0.02	<0.01	<0.02	<0.01	<0.01
	5103-71-9	alpha-Chlordane	<0.01	<0.02	<0.01	<0.02	<0.01	<0.02	<0.01	<0.01
	319-85-7	beta-BHC	<0.01	<0.02	<0.01	<0.02	<0.01	<0.02	<0.01	<0.01
	319-86-8	delta-BHC	<0.01	<0.02	<0.01	<0.02	<0.01	<0.02	<0.01	<0.01
	60-57-1	Dieldrin	<0.006	<0.012	<0.006	<0.012	<0.006	<0.012	<0.006	<0.006
	959-98-8	Endosulfan I	<0.01	<0.02	<0.01	<0.02	<0.01	<0.02	<0.01	<0.01
	33213-65-9	Endosulfan II	<0.01	<0.02	<0.01	<0.02	<0.01	<0.02	<0.01	<0.01
	1031-07-8	Endosulfan sulfate	<0.01	<0.02	<0.01	<0.02	<0.01	<0.02	<0.01	<0.01
	72-20-8	Endrin	<0.01	<0.02	<0.01	<0.02	<0.01	<0.02	<0.01	<0.01
	7421-93-4	Endrin aldehyde	<0.07	<0.14	<0.07	<0.14	<0.07	<0.14	<0.07	<0.07
	53494-70-5	Endrin ketone	<0.01	<0.02	<0.01	<0.02	<0.01	<0.02	<0.01	<0.01
	58-89-9	gamma-BHC	<0.01	<0.02	<0.01	<0.02	<0.01	<0.02	<0.01	<0.01
	5103-74-2	gamma-chlordane	<0.002	<0.004	<0.002	<0.004	<0.002	<0.004	<0.002	<0.002
	76-44-8	Heptachlor	<0.01	<0.02	<0.01	<0.02	<0.01	<0.02	<0.01	<0.01
	66240-71-9	Heptachlor epoxide	<0.01	<0.02	<0.01	<0.02	<0.01	<0.02	<0.01	<0.01
	465-73-6	Isodrin	<0.01	<0.02	<0.01	<0.02	<0.01	<0.02	<0.01	<0.01
	72-43-5	Methoxychlor	<0.006	<0.012	<0.006	<0.012	<0.006	<0.012	<0.006	<0.006
	72-54-8	pp-DDD	<0.006	<0.012	<0.006	<0.012	<0.006	<0.012	<0.006	<0.006
	72-55-9	pp-DDE	<0.006	<0.012	<0.006	<0.012	<0.006	<0.012	<0.006	<0.006
	50-29-3	pp-DDT	<0.006	<0.012	<0.006	<0.012	<0.006	<0.012	<0.006	<0.006
Herbicides (mg/L)	93-76-5	2,4,5-T	0.001	<0.003	0.001	<0.003	0.001	<0.002	<0.001	<0.002
	93-72-1	2,4,5-TP	<0.001	<0.003	<0.001	<0.003	<0.001	<0.003	<0.001	<0.001
	94-75-7	2,4-D	<0.001	<0.003	<0.001	<0.003	<0.001	<0.002	<0.001	<0.002
	94-82-6	2,4-DB	<0.001	<0.003	<0.001	<0.003	<0.001	<0.003	<0.001	<0.001
	1918-00-9	Dicamba	0.003	0.015	<0.003	0.004	<0.001	<0.002	<0.001	<0.002
	15165-67-0	Dichloroprop	<0.001	<0.003	<0.001	<0.003	<0.001	<0.003	<0.001	<0.001
	88-85-7	Dinoseb	<0.04	<0.08	<0.04	<0.08	<0.04	<0.08	<0.04	<0.04
	94-74-6	MCPA	<0.003	0.053	<0.003	<0.041	<0.002	<0.017	<0.002	0.002
	93-65-2	MCPP	<0.003	0.005	<0.003	0.004	0.001	<0.002	<0.001	<0.002

Chemical group	CAS Number	Chemical	F1 Fraction		F2 Fraction		F3 Fraction		F4 Fraction	
			Min	Max	Min	Max	Min	Max	Min	Max
	1918-02-1	Picloram	<0.001	<0.003	<0.001	<0.003	<0.001	<0.003	<0.001	<0.001
	55335-06-3	Triclopyr	<0.003	0.003	0.002	<0.003	0.001	<0.002	<0.001	<0.002
PCBs (mg/L)	12674-11-2	Aroclor 1016 (screen)	<0.008	<0.016	<0.008	<0.016	<0.008	<0.016	<0.008	<0.008
	11104-28-2	Aroclor 1221 (screen)	<0.008	<0.016	<0.008	<0.016	<0.008	<0.016	<0.008	<0.008
	11141-16-5	Aroclor 1232 (screen)	<0.008	<0.016	<0.008	<0.016	<0.008	<0.016	<0.008	<0.008
	53469-21-9	Aroclor 1242 (screen)	<0.008	<0.016	<0.008	<0.016	<0.008	<0.016	<0.008	<0.008
	12672-29-6	Aroclor 1248 (screen)	<0.008	<0.016	<0.008	<0.016	<0.008	<0.016	<0.008	<0.008
	11097-69-1	Aroclor 1254 (screen)	<0.008	<0.016	<0.008	<0.016	<0.008	<0.016	<0.008	<0.008
	11096-82-5	Aroclor 1260 (screen)	<0.008	<0.016	<0.008	<0.016	<0.008	<0.016	<0.008	<0.008
Nutrients (mg/L)	7664-41-7	Ammonia	160	520	46	100	19	25	0.26	9.8
	N/A	Free Reactive Phosphorus	5.1	8.0	2.7	9.8	4.4	8.6	3.1	3.4
	N/A	NOx-N	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
	7723-14-0	Phosphorus	8.8	20	4.7	12	5.2	9.9	3.5	3.9
Other	N/A	Conductivity (µS/cm)	11000	11000	2700	2700	610	610	460	460
	N/A	Dissolved Organic Carbon (mg/L)	6200	6200	nm	nm	nm	nm	nm	nm
	N/A	pH	6.8	6.8	6.8	6.8	7.4	7.4	7.6	7.6

nm, not measured

Table A5: Summary of chemical analysis of batch extractions generated from mixed waste organic outputs from Facility A

Chemical group	CAS Number	Chemical	No. of samples	No. Detects (% Detects)	Average[1]	Minimum	Maximum	Median[1]	95th percentile[1]
Metals (mg/L)	7429-90-5	Aluminium	5	5 (100)	2.2	2.0	2.4	2.1	2.4
	7440-36-0	Antimony	5	5 (100)	0.014	0.01	0.02	0.01	0.02
	7440-38-2	Arsenic	5	0 (0)		<0.03	<0.03		
	7440-39-3	Barium	5	5 (100)	0.056	0.04	0.08	0.05	0.076
	7440-41-7	Beryllium	5	0 (0)		<0.01	<0.01		
	7440-42-8	Boron	5	5 (100)	0.52	0.5	0.6	0.5	0.58
	7440-43-9	Cadmium	5	0 (0)		<0.01	<0.01		
	7440-47-3	Chromium	5	5 (100)	0.086	0.07	0.14	0.07	0.13
	7440-48-4	Cobalt	5	5 (100)	0.04	0.02	0.05	0.05	0.05
	7440-50-8	Copper	5	5 (100)	1.27	0.42	2.0	1.4	2.0
	7439-89-6	Iron	5	5 (100)	2.3	1.9	2.7	2.3	2.6
	7439-92-1	Lead	5	5 (100)	0.13	0.11	0.17	0.12	0.16
	7439-93-2	Lithium	5	3 (60)	0.02	0.02	<0.02	0.02	0.02
	7439-96-5	Manganese	5	5 (100)	1.4	0.59	1.8	1.6	1.8
	7439-97-6	Mercury (ug/L)	7	5 (100)	0.25	0.09	0.5	0.2	0.47
	7439-98-7	Molybdenum	5	5 (100)	0.038	0.03	0.04	0.04	0.04
	7440-02-0	Nickel	5	5 (100)	0.53	0.19	0.8	0.6	0.79
	7782-49-2	Selenium	5	0 (0)		<0.04	<0.04		
	7440-21-3	Silicon	5	5 (100)	2.5	1.8	4	2.1	3.8
	7440-22-4	Silver	5	0 (0)		<0.005	<0.005		
	7440-24-6	Strontium	5	5 (100)	0.41	0.39	0.42	0.42	0.42
	7704-34-9	Sulfur	5	5 (100)	72	67	86	69	82.8
	7440-28-0	Thallium	5	0 (0)					
	7440-31-5	Tin	5	1 (20)	0.03	<0.02	0.03	0.03	0.03
	7440-32-6	Titanium	5	5 (100)	0.034	0.03	0.05	0.03	0.046
	7440-62-2	Vanadium	5	1 (20)	0.01	<0.01	0.01	0.01	0.01
	7440-66-6	Zinc	5	5 (100)	2.6	1.1	3.5	3.2	3.5

Chemical group	CAS Number	Chemical	No. of samples	No. Detects (% Detects)	Average[1]	Minimum	Maximum	Median[1]	95th percentile[1]
Major cations (mg/L)	7440-70-2	Calcium	5	5 (100)	180	150	190	180	190
	7439-95-4	Magnesium	5	5 (100)	26	23	29	27	29
	7440-09-7	Potassium	5	5 (100)	170	160	180	170	180
	7440-23-5	Sodium	5	5 (100)	220	200	260	200	250
Major anions (mg/L)	N/A	Chloride	6	6 (100)	200	180	230	200	230
	N/A	Sulfate	5	5 (100)	180	170	220	180	210
PAHs (mg/L)	83-32-9	Acenaphthene	7	0 (0)		<0.002	<0.008		
	208-96-8	Acenaphthylene	7	0 (0)		<0.002	<0.008		
	120-12-7	Anthracene	7	0 (0)		<0.002	<0.008		
	56-55-3	Benzo (a) anthracene	7	0 (0)		<0.002	<0.008		
	50-32-8	Benzo (a) pyrene	7	0 (0)		<0.001	<0.004		
	205-99-2	Benzo (b) fluoranthene	7	0 (0)		<0.001	<0.004		
	191-24-2	Benzo (ghi) perylene	7	0 (0)		<0.001	<0.004		
	207-08-9	Benzo (k) fluoranthene	7	0 (0)		<0.001	<0.004		
	218-01-9	Chrysene	7	0 (0)		<0.001	<0.004		
	53-70-3	Dibenzo (ah) anthracene	7	0 (0)		<0.001	<0.004		
	206-44-0	Fluoranthene	7	0 (0)		<0.005	<0.02		
	86-73-7	Fluorene	7	0 (0)		<0.002	<0.008		
	193-39-5	Indeno (123cd) pyrene	7	0 (0)		<0.001	<0.004		
	91-20-3	Naphthalene	7	0 (0)		<0.002	<0.008		
	198-55-0	Perylene	7	0 (0)		<0.001	<0.004		
	85-01-8	Phenanthrene	7	0 (0)		<0.002	<0.008		
	129-00-0	Pyrene	7	0 (0)		<0.001	<0.004		
Phenols (mg/L)	58-90-2	2,3,4,6-Tetrachlorophenol	7	0 (0)		<0.01	<0.04		
	95-95-4	2,4,5-Trichlorophenol	7	0 (0)		<0.005	<0.02		
	88-06-2	2,4,6-Trichlorophenol	7	0 (0)		<0.005	<0.02		
	120-83-2	2,4-Dichlorophenol	7	0 (0)		<0.005	<0.02		

Chemical group	CAS Number	Chemical	No. of samples	No. Detects (% Detects)	Average[1]	Minimum	Maximum	Median[1]	95th percentile[1]
	105-67-9	2,4-Dimethylphenol	7	0 (0)		<0.005	<0.02		
	51-28-5	2,4-Dinitrophenol	7	0 (0)		<0.2	<0.8		
	121-14-2	2,4-Dinitrotoluene	7	0 (0)		<0.01	<0.04		
	87-65-0	2,6-Dichlorophenol	7	0 (0)		<0.005	<0.02		
	95-57-8	2-Chlorophenol	7	0 (0)		<0.003	<0.012		
	534-52-1	2-Methyl-4,6-dinitrophenol	7	0 (0)		<0.03	<0.12		
	95-48-7	2-Methylphenol	7	0 (0)		<0.005	<0.02		
	88-75-5	2-Nitrophenol	7	0 (0)		<0.005	<0.02		
	108-39-4 and 106-44-5	3+4-Methylphenol	7	6 (86)	0.041	<0.02	0.14	0.018	0.115
	59-50-7	4-Chloro-3-methylphenol	7	0 (0)		<0.005	<0.02		
	100-02-7	4-Nitrophenol	7	0 (0)		<0.03	<0.12		
	87-86-5	Pentachlorophenol	7	0 (0)		<0.005	<0.02		
	108-95-2	Phenol	7	7 (100)	0.391	0.2	1	0.31	0.814
Phthalates (mg/L)	85-68-7	Benzyl butyl phthalate	2	0 (0)		<0.004	<0.08		
	103-23-1	Bis-2-ethylhexyl adipate	7	1 (14)	0.012	<0.24	<0.48[a]		
	117-81-7	Bis-2-ethylhexyl phthalate	7	1 (14)	0.038	<0.12	<0.24[b]		
	84-74-2	Dibutyl phthalate	7	0 (0)		<0.003	<0.08		
	84-66-2	Diethyl phthalate	2	0 (0)		<0.020	<0.08		
	131-11-3	Dimethyl phthalate	2	0 (0)		<0.020	<0.08		
	117-84-0	Di-n-octyl phthalate	2	0 (0)		<0.004	<0.08		
Chlorobenzenes (mg/L)	634-66-2	1,2,3,4-Tetrachlorobenzene	7	0 (0)		<0.001	<0.004		
	95-94-3	1,2,4,5-Tetrachlorobenzene	7	0 (0)		<0.005	<0.02		
	120-82-1	1,2,4-Trichlorobenzene	7	0 (0)		<0.005	<0.02		
	95-50-1	1,2-Dichlorobenzene	7	0 (0)		<0.003	<0.012		
	106-46-7	1,4-Dichlorobenzene	7	0 (0)		<0.003	<0.012		
	118-74-1	Hexachlorobenzene	7	0 (0)		<0.002	<0.008		
	608-93-5	Pentachlorobenzene	7	0 (0)		<0.005	<0.02		

Chemical group	CAS Number	Chemical	No. of samples	No. Detects (% Detects)	Average[1]	Minimum	Maximum	Median[1]	95th percentile[1]
Nitrobenzenes (mg/L)	98-95-3	Nitrobenzene	7	0 (0)		<0.005	<0.02		
	82-68-8	Pentachloronitrobenzene	7	0 (0)		<0.005	<0.02		
Pesticides (mg/L)	309-00-2	Aldrin	7	0 (0)		<0.005	<0.02		
	319-84-6	alpha-BHC	7	0 (0)		<0.005	<0.02		
	5103-71-9	alpha-Chlordane	7	0 (0)		<0.005	<0.02		
	319-85-7	beta-BHC	7	0 (0)		<0.005	<0.02		
	2921-88-2	Chlorpyrifos	1	0 (0)		<0.005	<0.02		
	319-86-8	delta-BHC	7	0 (0)		<0.005	<0.02		
	60-57-1	Dieldrin	7	0 (0)		<0.003	<0.012		
	959-98-8	Endosulfan I	7	0 (0)		<0.005	<0.02		
	33213-65-9	Endosulfan II	7	0 (0)		<0.005	<0.02		
	1031-07-8	Endosulfan sulfate	7	0 (0)		<0.005	<0.02		
	72-20-8	Endrin	7	0 (0)		<0.005	<0.02		
	7421-93-4	Endrin aldehyde	7	0 (0)		<0.035	<0.14		
	53494-70-5	Endrin ketone	7	0 (0)		<0.005	<0.02		
	58-89-9	gamma-BHC	7	0 (0)		<0.005	<0.02		
	5103-74-2	gamma-chlordane	7	0 (0)		<0.001	<0.004		
	76-44-8	Heptachlor	7	0 (0)		<0.005	<0.02		
	66240-71-9	Heptachlor epoxide	7	0 (0)		<0.005	<0.02		
	465-73-6	Isodrin	7	0 (0)		<0.005	<0.02		
	72-43-5	Methoxychlor	7	0 (0)		<0.003	<0.012		
	72-54-8	pp-DDD	7	0 (0)		<0.003	<0.012		
	72-55-9	pp-DDE	7	0 (0)		<0.003	<0.012		
	50-29-3	pp-DDT	7	0 (0)		<0.003	<0.012		
Herbicides (mg/L)	93-76-5	2,4,5-T	6	0 (0)		<0.001	<0.003		
	93-72-1	2,4,5-TP	6	0 (0)		<0.001	<0.003		
	94-75-7	2,4-D	6	1 (17)	0.016	<0.001	0.016		
	94-82-6	2,4-DB	6	0 (0)		<0.001	<0.003		

Chemical group	CAS Number	Chemical	No. of samples	No. Detects (% Detects)	Average[1]	Minimum	Maximum	Median[1]	95th percentile[1]
	1918-00-9	Dicamba	6	6 (100)	0.0035	0.003	0.004	0.0035	0.004
	15165-67-0	Dichloroprop	6	0 (0)		<0.001	<0.003		
	88-85-7	Dinoseb	7	0 (0)		<0.02	<0.08		
	94-74-6	MCPA	6	6 (100)	0.025	0.018	0.032	0.024	0.003
	93-65-2	MCPP	6	2 (33)	0.0045	<0.001	0.005		
	1918-02-1	Picloram	6	0 (0)		<0.001	<0.003		
	55335-06-3	Triclopyr	6	3 (50)	0.0017	<0.001	0.003	0.001	0.0028
PCBs (mg/L)	12674-11-2	Aroclor 1016 (screen)	7	0 (0)		<0.004	<0.016		
	11104-28-2	Aroclor 1221 (screen)	7	0 (0)		<0.004	<0.016		
	11141-16-5	Aroclor 1232 (screen)	7	0 (0)		<0.004	<0.016		
	53469-21-9	Aroclor 1242 (screen)	7	0 (0)		<0.004	<0.016		
	12672-29-6	Aroclor 1248 (screen)	7	0 (0)		<0.004	<0.016		
	11097-69-1	Aroclor 1254 (screen)	7	0 (0)		<0.004	<0.016		
	11096-82-5	Aroclor 1260 (screen)	7	0 (0)		<0.004	<0.016		
Alkylphenols (mg/L)	84852-15-3	4-Nonylphenol	2	0 (0)		<0.006	<0.024		
	140-66-9	4-tert-Octylphenol	1	0 (0)		<0.024	<0.024		
	80-05-7	Bisphenol A	2	2 (100)	0.145	0.12	0.17		
Organotins (µg/L)	78763-54-9	Monobutyl tin	3	1 (33)	0.008	0.008	<0.01[c]		
	1191-48-6	Dibutyl tin	3	0 (0)		<0.002	<0.01		
	688-73-3	Tributyl tin	3	0 (0)		<0.002	<0.01		
PBDEs (ng/Kg)	N/A	Total PBDEs	4	4 (100)	17.55	2.7	40	13.75	37.45
	N/A	Tri-BDE	4	0 (0)		<0.53			
	N/A	Tetra-BDE	4	3 (75)	3.1	<2.35	6.6	2.9	6.2
	N/A	Penta-BDE	4	3 (75)	3.1	<2.59	7.3	2.5	6.6
	N/A	Hexa-BDE	4	3 (75)	2.3	<2.2	6.3	1.5	5.7
	N/A	Hepta-BDE	4	3 (75)	5.9	<3.0	18	2.7	16

Chemical group	CAS Number	Chemical	No. of samples	No. Detects (% Detects)	Average[1]	Minimum	Maximum	Median[1]	95th percentile[1]
	N/A	Octa-BDE	4	3 (75)	3.2	<2.8	9.1	1.9	8.2
	N/A	Nona-BDE	4	0 (0)		<2.7			
	N/A	Deca-BDE	4	0 (0)		<20			
Perfluorinated compounds (µg/L)	1763-23-1	PFOA	1	0 (0)		<1.0	<1.0		
	335-67-1	PFOs	1	0 (0)		<1.0	<1.0		
Nutrients (mg/L)	7664-41-7	Ammonia	6	6 (100)	76.50	54	88	83	87
	N/A	Free Reactive Phosphorus	6	6 (100)	0.832	0.3	1.4	0.81	1.2675
	N/A	NOx-N	6	3 (50)	5.43	<0.02	5.6	5.6	5.6
	7723-14-0	Phosphorus	7	5 (100)	3.8	3.0	4.1	4.0	4.1
Other	N/A	Conductivity (µS/cm)	2	2 (100)	2497	2343	2650		
	N/A	pH	1	1 (100)	6.61	6.61	6.61		

[1] only concentrations that were above the limit of quantification were used to calculate the average, median and 95th percentile concentrations

Maximum measured concentrations of:

[a] bis-2-ethylhexyl adipate 0.012 mg/L

[b] bis-2-ethylhexyl phthalate 0.038 mg/L

[c] monobutyl tin 8 ng/L

Table A6: Summary of chemical analysis of batch extractions generated from mixed waste organic outputs from Facility B

Chemical group	CAS Number	Chemical	No. of samples	No. Detects (% Detects)	Average[1]	Minimum	Maximum	Median[1]	95th percentile[1]
Metals (mg/L)	7429-90-5	Aluminium	8	8 (100)	2.5	0.91	4.7	2.6	4.0
	7440-36-0	Antimony	8	8 (100)		<0.01	<0.01		
	7440-38-2	Arsenic	8	0 (0)		<0.03	<0.03		
	7440-39-3	Barium	8	6 (75)	0.063	0.04	0.14	0.05	0.12
	7440-41-7	Beryllium	8	0 (0)		<0.01	<0.01		
	7440-42-8	Boron	8	8 (100)	0.41	0.3	0.5	0.4	0.5
	7440-43-9	Cadmium	8	0 (0)		<0.01	<0.01		
	7440-47-3	Chromium	8	8 (100)	0.03	0.02	0.05	0.025	0.047
	7440-48-4	Cobalt	8	6 (75)	0.015	0.01	0.02	0.015	0.02
	7440-50-8	Copper	8	8 (100)	0.28	0.14	0.43	0.23	0.42
	7439-89-6	Iron	8	8 (100)	3.8	2.8	6.2	3.6	5.5
	7439-92-1	Lead	8	8 (100)	0.05	0.02	0.09	0.05	0.083
	7439-93-2	Lithium	8	1 (13)	0.02	<0.02	0.02		
	7439-96-5	Manganese	8	8 (100)	0.79	0.15	1.4	0.8	1.4
	7439-97-6	Mercury (ug/L)	10	9 (90)	0.25	0.06	0.59	0.17	0.55
	7439-98-7	Molybdenum	8	8 (100)	0.023	0.01	0.03	0.02	0.03
	7440-02-0	Nickel	8	8 (100)	0.14	0.07	0.23	0.1	0.23
	7782-49-2	Selenium	8	0 (0)		<0.04	<0.04		
	7440-21-3	Silicon	8	0 (0)		<0.04	<0.04		
	7440-22-4	Silver	8	0 (0)		<0.005	<0.005		
	7440-24-6	Strontium	8	8 (100)	0.23	0.08	0.42	0.18	0.41
	7704-34-9	Sulfur	8	8 (100)	48	30	65	46	64
	7440-28-0	Thallium	8	0 (0)		<0.03	<0.03		
	7440-31-5	Tin	8	0 (0)		<0.02	<0.02		
	7440-32-6	Titanium	8	8 (100)	0.038	0.02	0.06	0.03	0.06
	7440-62-2	Vanadium	8	7 (88)	0.016	0.01	0.02	0.02	0.02
	7440-66-6	Zinc	8	8 (100)	1.6	0.29	3.0	1.2	3.0

Chemical group	CAS Number	Chemical	No. of samples	No. Detects (% Detects)	Average[1]	Minimum	Maximum	Median[1]	95th percentile[1]
Major cations (mg/L)	7440-70-2	Calcium	8	8 (100)	130	44	250	100	250
	7439-95-4	Magnesium	8	8 (100)	27	12	38	29	37
	7440-09-7	Potassium	8	8 (100)	210	150	270	190	260
	7440-23-5	Sodium	8	8 (100)	180	150	190	180	190
Major anions (mg/L)	N/A	Chloride	9	9 (100)	200	170	270	190	260
	N/A	Sulfate	8	8 (100)	110	58	170	100	170
PAHs (mg/L)	83-32-9	Acenaphthene	9	0 (0)		<0.002	<0.008		
	208-96-8	Acenaphthylene	9	0 (0)		<0.002	<0.008		
	120-12-7	Anthracene	9	0 (0)		<0.002	<0.008		
	56-55-3	Benzo (a) anthracene	9	0 (0)		<0.002	<0.008		
	50-32-8	Benzo (a) pyrene	9	0 (0)		<0.001	<0.004		
	205-99-2	Benzo (b) fluoranthene	9	0 (0)		<0.001	<0.004		
	191-24-2	Benzo (ghi) perylene	9	0 (0)		<0.001	<0.004		
	207-08-9	Benzo (k) fluoranthene	9	0 (0)		<0.001	<0.004		
	218-01-9	Chrysene	9	0 (0)		<0.001	<0.004		
	53-70-3	Dibenzo (ah) anthracene	9	0 (0)		<0.001	<0.004		
	206-44-0	Fluoranthene	9	0 (0)		<0.005	<0.02		
	86-73-7	Fluorene	9	0 (0)		<0.002	<0.008		
	193-39-5	Indeno (123cd) pyrene	9	0 (0)		<0.001	<0.004		
	91-20-3	Naphthalene	9	0 (0)		<0.002	<0.008		
	198-55-0	Perylene	9	0 (0)		<0.001	<0.004		
	85-01-8	Phenanthrene	9	0 (0)		<0.002	<0.008		
	129-00-0	Pyrene	9	0 (0)		<0.001	<0.004		
Phenols (mg/L)	58-90-2	2,3,4,6-Tetrachlorophenol	9	0 (0)		<0.01	<0.04		
	95-95-4	2,4,5-Trichlorophenol	9	0 (0)		<0.005	<0.02		
	88-06-2	2,4,6-Trichlorophenol	9	0 (0)		<0.005	<0.02		
	120-83-2	2,4-Dichlorophenol	9	0 (0)		<0.005	<0.02		

Chemical group	CAS Number	Chemical	No. of samples	No. Detects (% Detects)	Average[1]	Minimum	Maximum	Median[1]	95th percentile[1]
	105-67-9	2,4-Dimethylphenol	9	0 (0)		<0.005	<0.02		
	51-28-5	2,4-Dinitrophenol	9	0 (0)		<0.2	<0.8		
	121-14-2	2,4-Dinitrotoluene	9	0 (0)		<0.01	<0.04		
	87-65-0	2,6-Dichlorophenol	9	0 (0)		<0.005	<0.02		
	95-57-8	2-Chlorophenol	9	0 (0)		<0.003	<0.012		
	534-52-1	2-Methyl-4,6-dinitrophenol	9	0 (0)		<0.03	<0.12		
	95-48-7	2-Methylphenol	9	0 (0)		<0.005	<0.02		
	88-75-5	2-Nitrophenol	9	0 (0)		<0.005	<0.02		
	108-39-4 and 106-44-5	3+4-Methylphenol	9	7 (78)	0.13	0.048	0.17	0.14	0.16
	59-50-7	4-Chloro-3-methylphenol	9	0 (0)		<0.005	<0.02		
	100-02-7	4-Nitrophenol	9	0 (0)		<0.03	<0.12		
	87-86-5	Pentachlorophenol	9	0 (0)		<0.005	<0.02		
	108-95-2	Phenol	9	7 (78)	0.32	0.12	0.64	0.33	0.57
Phthalates (mg/L)	85-68-7	Benzyl butyl phthalate	2	0 (0)		<0.08	<0.08		
	103-23-1	Bis-2-ethylhexyl adipate	9	1 (11)	0.012	0.012	<0.48[a]		
	117-81-7	Bis-2-ethylhexyl phthalate	9	1 (11)	0.019	0.019	<0.24[b]		
	84-74-2	Dibutyl phthalate	9	1 (11)	0.003	0.003	<0.08[c]		
	84-66-2	Diethyl phthalate	3	2 (67)	0.022	0.022	<0.08[d]		
	131-11-3	Dimethyl phthalate	3	0 (0)		<0.02	<0.08		
	117-84-0	Di-n-octyl phthalate	3	0 (0)		<0.004	<0.08		
Chlorobenzenes (mg/L)	634-66-2	1,2,3,4-Tetrachlorobenzene	6	0 (0)		<0.001	<0.004		
	95-94-3	1,2,4,5-Tetrachlorobenzene	6	0 (0)		<0.005	<0.02		
	120-82-1	1,2,4-Trichlorobenzene	6	0 (0)		<0.005	<0.02		
	95-50-1	1,2-Dichlorobenzene	6	0 (0)		<0.003	<0.012		
	106-46-7	1,4-Dichlorobenzene	6	0 (0)		<0.003	<0.012		
	118-74-1	Hexachlorobenzene	6	0 (0)		<0.002	<0.008		
	608-93-5	Pentachlorobenzene	6	0 (0)		<0.005	<0.02		

Chemical group	CAS Number	Chemical	No. of samples	No. Detects (% Detects)	Average[1]	Minimum	Maximum	Median[1]	95th percentile[1]
Nitrobenzenes (mg/L)	98-95-3	Nitrobenzene	9	0 (0)		<0.005	<0.02		
	82-68-8	Pentachloronitrobenzene	8	0 (0)		<0.005	<0.02		
Pesticides (mg/L)	309-00-2	Aldrin	8	0 (0)		<0.005	<0.02		
	319-84-6	alpha-BHC	8	0 (0)		<0.005	<0.02		
	5103-71-9	alpha-Chlordane	8	0 (0)		<0.005	<0.02		
	319-85-7	beta-BHC	8	0 (0)		<0.005	<0.02		
	2921-88-2	Chlorpyrifos	3	0 (0)		<0.005	<0.02		
	319-86-8	delta-BHC	8	0 (0)		<0.005	<0.02		
	60-57-1	Dieldrin	8	0 (0)		<0.003	<0.012		
	959-98-8	Endosulfan I	8	0 (0)		<0.005	<0.02		
	33213-65-9	Endosulfan II	8	0 (0)		<0.005	<0.02		
	1031-07-8	Endosulfan sulfate	8	0 (0)		<0.005	<0.02		
	72-20-8	Endrin	8	0 (0)		<0.005	<0.02		
	7421-93-4	Endrin aldehyde	8	0 (0)		<0.035	<0.14		
	53494-70-5	Endrin ketone	8	0 (0)		<0.005	<0.02		
	58-89-9	gamma-BHC	8	0 (0)		<0.005	<0.02		
	5103-74-2	gamma-chlordane	8	0 (0)		<0.001	<0.004		
	76-44-8	Heptachlor	8	0 (0)		<0.005	<0.02		
	66240-71-9	Heptachlor epoxide	8	0 (0)		<0.005	<0.02		
	465-73-6	Isodrin	8	0 (0)		<0.005	<0.02		
	72-43-5	Methoxychlor	8	0 (0)		<0.003	<0.012		
	72-54-8	pp-DDD	8	0 (0)		<0.003	<0.012		
	72-55-9	pp-DDE	8	0 (0)		<0.003	<0.012		
	50-29-3	pp-DDT	8	0 (0)		<0.003	<0.012		
Herbicides (mg/L)	93-76-5	2,4,5-T	8	0 (0)		<0.001	<0.003		
	93-72-1	2,4,5-TP	8	0 (0)		<0.001	<0.003		
	94-75-7	2,4-D	8	0 (0)		<0.001	<0.003		
	94-82-6	2,4-DB	8	0 (0)		<0.001	<0.003		

Chemical group	CAS Number	Chemical	No. of samples	No. Detects (% Detects)	Average[1]	Minimum	Maximum	Median[1]	95th percentile[1]
	1918-00-9	Dicamba	8	5 (63)	0.0042	<0.003	0.005	0.004	0.0048
	15165-67-0	Dichloroprop	8	0 (0)		<0.001	<0.003		
	88-85-7	Dinoseb (mg/L)	6	0 (0)		<0.02	<0.08		
	94-74-6	MCPA	8	8 (75)	0.02	<0.003	0.027	0.024	0.027
	93-65-2	MCPP	8	4 (50)	0.003	<0.003	0.003	0.003	0.003
	1918-02-1	Picloram	8	0 (0)		<0.001	<0.003		
	55335-06-3	Triclopyr	8	3 (38)	0.0013	0.001	<0.003[e]	0.001	0.0019
PCBs (mg/L)	12674-11-2	Aroclor 1016 (screen)	9	0 (0)		<0.004	<0.016		
	11104-28-2	Aroclor 1221 (screen)	9	0 (0)		<0.004	<0.016		
	11141-16-5	Aroclor 1232 (screen)	9	0 (0)		<0.004	<0.016		
	53469-21-9	Aroclor 1242 (screen)	9	0 (0)		<0.004	<0.016		
	12672-29-6	Aroclor 1248 (screen)	9	0 (0)		<0.004	<0.016		
	11097-69-1	Aroclor 1254 (screen)	9	0 (0)		<0.004	<0.016		
	11096-82-5	Aroclor 1260 (screen)	9	0 (0)		<0.004	<0.016		
Alkylphenols (mg/L)	84852-15-3	4-Nonylphenol	3	0 (0)		<0.006	<0.024		
	140-66-9	4-tert-Octylphenol	3	0 (0)		<0.006	<0.024		
	80-05-7	Bisphenol A	3	0 (0)		<0.03	<0.12		
Organotins (µg/L)	78763-54-9	Monobutyl tin	3	1 (67)	0.005	<0.005	<0.01[f]		
	1191-48-6	Dibutyl tin	3	0 (0)		<0.002	<0.01		
	688-73-3	Tributyl tin	3	0 (0)		<0.002	<0.01		
PBDEs (ng/Kg)	N/A	Total PBDEs	4	4 (100)	14	1	25	16	24
	N/A	Tri-BDE	4	0 (0)		<0.53			
	N/A	Tetra-BDE	4	2 (50)	2.0	<2.35	5.0		
	N/A	Penta-BDE	4	2 (50)	1.7	<2.59	3.7		
	N/A	Hexa-BDE	4	3 (75)	1.7	<2.2	4.7	1.0	4.2
	N/A	Hepta-BDE	4	4 (100)	5.7	<3.0	14	4.5	13

Chemical group	CAS Number	Chemical	No. of samples	No. Detects (% Detects)	Average[1]	Minimum	Maximum	Median[1]	95th percentile[1]
	N/A	Octa-BDE	4	3 (75)	2.7	<2.8	6.1	2.4	5.9
	N/A	Nona-BDE	4	0 (0)		<2.7			
	N/A	Deca-BDE	4	0 (0)		<20			
Perfluorinated compounds (µg/L)	1763-23-1	PFOA	1	0 (0)		<1.0	<1.0		
	335-67-1	PFOs	1	0 (0)		<1.0	<1.0		
Nutrients (mg/L)	7664-41-7	Ammonia	9	9 (100)	82	51	100	83	100
	N/A	Free Reactive Phosphorus	9	9 (100)	2.3	0.81	8.0	1.5	6.1
	N/A	NOx-N	9	1 (11)	0.38	<0.02	0.38		
	7723-14-0	Phosphorus	8	8 (100)	3.5	2.2	6.0	3.3	5.1
Other	N/A	Conductivity (µS/cm)	nm	nm	nm	nm	nm	nm	nm
	N/A	pH	nm	nm	nm	nm	nm	nm	nm

[1] only concentrations that were above the limit of quantification were used to calculate the average, median and 95th percentile concentrations

nm, not measured

Maximum measured concentrations of:

[a] bis-2-ethylhexyl adipate 0.012 mg/L

[b] bis-2-ethylhexyl phthalate 0.019 mg/L

[c] dibutyl phthalate 0.003 mg/L

d diethyl phthalate 0.022 mg/L

e triclopyr 0.0013 mg/L

f monobutyl tin 0.005 µg/L

Appendix B – summary of toxicity data used for assessment factor approach

Summary of final values used for the preliminary screening assessment and hazard assessment

Table A7: Summary of lowest toxicity data, assessment factors and resulting criteria concentrations for all chemicals that used the assessment factor approach to derive criteria concentrations

Media	Chemical	Lowest toxicity data (mg/kg)	Assessment Factor*	Criteria concentration
Terrestrial	Metalaxyl	16.6	10	1.66
	Thiabendazole	2.1	10	0.21
	2,4-D	3	10	0.3
	MCPA	26.7	10	2.67
	MCPP	988	500	2.0
	Tributyl tin	1.3	10	0.13
Aquatic	MCPP	6	10	0.6
	Triclopyr	4.6	10	0.46

* In some cases there is sufficient toxicity data to develop a species sensitivity distribution to derive criteria concentrations, however the assessment factor approach was still used as in many cases the original sources of the toxicity data have not been checked. This is due to limited information being provided in many of the sources listed in the tables below and the high number of acute data rather than chronic data.

Terrestrial toxicity data

Table A8: List of terrestrial toxicity data available for metalaxyl

Toxicity (mg/kg)	Measure	Endpoint	Acute/chronic	Species	Source of data
830	LC50	mortality	acute (14 days)	*Eisenia fetida* (earthworm)	EFSA (2015)
>1000	LC50	mortality	acute (14 days)	*Eisenia fetida* (earthworm)	EFSA (2015)
35.63	NOEC		chronic (8 weeks)	*Eisenia fetida* (earthworm)	EFSA (2015)
89	NOEC		chronic	*Eisenia fetida* (earthworm)	EFSA (2015)
16.6	**EC10**		**chronic**	***Hypoaspis* aculeifer (soil mite)**	**EFSA (2015)**
125	NOEC		chronic	*Folsomia candida* (collembola)	EFSA (2015)
89	NOEC		chronic	*Folsomia candida* (collembola)	EFSA (2015)

Table A9: List of terrestrial toxicity data available for thiabendazole

Toxicity (mg/kg)	Measure	Endpoint	Acute/chronic	Species	Source of data
>1000	LC50	mortality	acute	earthworm	European Commission (2001a)
4.2	NOEC	reproduction	chronic	earthworm	European Commission (2001a)
>224.4	LC50		acute (14 days)	*Eisenia fetida* (earthworm)	EFSA (2014a)
2.1	**NOEC**		**chronic (8 weeks)**	***Eisenia fetida* (earthworm)**	**EFSA (2014a)**
25	NOEC		chronic	*Folsomia candida* (collembola)	EFSA (2014a)
9	NOEC	Nitrogen mineralisation		Soil microorganisms	European Commission (2001a)
9	NOEC	Carbon mineralisation		Soil microorganisms	European Commission (2001a)

Table A10: List of terrestrial toxicity data available for 2,4-D

Toxicity (mg/kg)	Measure	Endpoint	Acute/chronic	Species	Source of data
350			acute	earthworm	European Commissions (2001b)
62.5	NOEC		chronic (8 weeks)	*Eisenia fetida* (earthworm)	EFSA (2014b)
>618	LC50	mortality	acute (14 days)	*Eisenia fetida* (earthworm)	EFSA (2014b)
10	NOEC		chronic	*Hypoapis aculeifer* (soil mite)	EFSA (2014b)
5	NOEC		chronic	*Hypoapis aculeifer* (soil mite)	EFSA (2014b)
10	NOEC		chronic	*Folsomia candida* (collembola)	EFSA (2014b)
1.25	NOEC		chronic	*Folsomia candida* (collembola)	EFSA (2014b)
29.9	NOEC	Nitrogen mineralisation	chronic (56 days)	Soil microorganisms	EFSA (2014b)
5	NOEC	Nitrogen mineralisation	chronic (28 days)	Soil microorganisms	EFSA (2014b)
5	NOEC	Nitrogen mineralisation	chronic (42 days)	Soil microorganisms	EFSA (2014b)
3	**NOEC**	**Carbon mineralisation**	**chronic (28 days)**	**Soil microorganisms**	**EFSA (2014b)**
29.9	NOEC	Carbon mineralisation	chronic (28 days)	Soil microorganisms	EFSA (2014b)
5	NOEC	Carbon mineralisation	chronic (28 days)	Soil microorganisms	EFSA (2014b)

Table A11: List of terrestrial toxicity data available for MCPA

Toxicity (mg/kg)	Measure	Endpoint	Acute/chronic	Species	Source of data
325	LC50	mortality	acute (14 days)	earthworm	European Commission (2008)
26.7	**NOEC**	**Nitrogen mineralisation**	**chronic (28 days)**	**Soil microorganisms**	**European Commission (2008)**
26.7	**NOEC**	**Carbon mineralisation**	**chronic (28 days)**	**Soil microorganisms**	**European Commission (2008)**
500*	LC0	mortality	acute (14 days)	*Eisenia fetida* (earthworm)	Kaczynska & Cycon (2004)
753*	LC50	mortality	acute (14 days)	*Eisenia fetida* (earthworm)	Kaczynska & Cycon (2004)

Toxicity (mg/kg)	Measure	Endpoint	Acute/chronic	Species	Source of data
>1000*	LC100	mortality	acute (14 days)	*Eisenia fetida* (earthworm)	Kaczynska & Cycon (2004)

* concentration reported for pesticide formulation (content of active substance reported to be 500 g/dm^3)

Table A12: List of terrestrial toxicity data available for MCPP

Toxicity (mg/kg)	Measure	Endpoint	Acute/chronic	Species	Source of data
988	**LC50**	**mortality**	**acute**	**earthworm**	**European Commission (2003)**

Table A13: List of terrestrial toxicity data available for tributyl tin

Toxicity (mg/kg)	Measure	Endpoint	Acute/ chronic	Species	Source of data
>1000*	EC50	C cycle (basal respiration)		Soil microorganisms	Hund-Rinke and Simon (2004)
>1000*	EC50	C cycle (substrate induced respiration)		Soil microorganisms	Hund-Rinke and Simon (2004)
11*	EC50	N cycle (potential ammonium oxidation)		Soil microorganisms	Hund-Rinke and Simon (2004)
64*	EC50	N cycle (potential ammonium oxidation)		Soil microorganisms	Hund-Rinke and Simon (2004)
156*	EC50	N cycle (potential ammonium oxidation)		Soil microorganisms	Hund-Rinke and Simon (2004)
22*	EC50	Reproduction		*Folsomia candida* (collembola)	Hund-Rinke and Simon (2004)
11*	EC50	Reproduction		*Folsomia candida* (collembola)	Hund-Rinke and Simon (2004)
66*	EC50	Reproduction		*Folsomia candida* (collembola)	Hund-Rinke and Simon (2004)
1.3*	**EC50**	**Reproduction**		***Eisenia fetida* (earthworm)**	**Hund-Rinke and Simon (2004)**
3.0*	EC50	Reproduction		*Eisenia fetida* (earthworm)	Hund-Rinke and Simon (2004)

Toxicity (mg/kg)	Measure	Endpoint	Acute/ chronic	Species	Source of data
2.7*	EC50	Reproduction		*Eisenia fetida* (earthworm)	Hund-Rinke and Simon (2004)
25*	EC50	Biomass		*Brassica rapa* (field mustard)	Hund-Rinke and Simon (2004)
16*	EC50	Biomass		*Brassica rapa* (field mustard)	Hund-Rinke and Simon (2004)
39*	EC50	Biomass		*Brassica rapa* (field mustard)	Hund-Rinke and Simon (2004)
452*	EC50	Biomass		*Avena sativa* (oat)	Hund-Rinke and Simon (2004)
553*	EC50	Biomass		*Avena sativa* (oat)	Hund-Rinke and Simon (2004)
687*	EC50	Biomass		*Avena sativa* (oat)	Hund-Rinke and Simon (2004)

* based on nominal concentrations

Aquatic toxicity data

Table A14: List of aquatic toxicity data available for MCPP

Toxicity (mg/L)	Measure	Endpoint	Acute/chronic	Species	Source of data
240	LC50	mortality	acute (4 days)	fish	European Commission (2003)
109	NOEC		chronic (21 days)	fish	European Commission (2003)
>200	EC50		acute (2 days)	Invertebrate	European Commission (2003)
22	NOEC	reproduction	chronic (21 days)	Invertebrate	European Commission (2003)
237	EC50	biomass	acute (3 days)	Algae	European Commission (2003)
40.2	EC50	Growth rate	acute (7 days)	Aquatic plant	European Commission (2003)
>10*	LC50	mortality	chronic (8 days)	*Daphnia magna* (water flea)	Matsumoto et al. (2009)
>10*	LC50	immobilisation	acute (1 day)	*Daphnia magna* (water flea)	Matsumoto et al. (2009)
>10*	LC50	immobilisation	acute (2 days)	*Daphnia magna* (water flea)	Matsumoto et al. (2009)
6*	**EC50**	**biomass**	**chronic (7 days)**	***Lemna minor* (duckweed)**	**Nitschke et al. (1999)**

*concentrations based on pesticide formulations

Table A15: List of aquatic toxicity data available for triclopyr

Toxicity (mg/L)	Measure	Endpoint	Acute/chronic	Species	Source of data
>521	LC50/NOEC		acute	earthworm	EFSA (2005)
>983	LC50/NOEC		acute	earthworm	EFSA (2005)
9.8	LC50/NOEC		acute	earthworm	EFSA (2005)
555	LC50/NOEC		acute	earthworm	EFSA (2005)
4.6	**LC50/NOEC**		**chronic**	**earthworm**	**EFSA (2005)**

Toxicity (mg/L)	Measure	Endpoint	Acute/chronic	Species	Source of data
9.6	LC50/NOEC		chronic	earthworm	EFSA (2005)
>8.5	NOEC	Nitrogen mineralisation	chronic (35 days)	Soil microorganisms	EFSA (2005)
4.15	Soil effects <25%	Nitrogen mineralisation	chronic (100 days)	Soil microorganisms	EFSA (2005)
>8.5	NOEC	Carbon mineralisation	chronic (35 days)	Soil microorganisms	EFSA (2005)
4.15	Soil effects <25%	Carbon mineralisation	chronic (29 days)	Soil microorganisms	EFSA (2005)
13.3	LC50	mortality	acute (1 day)	*Oncorhynchus gorbuscha* (pink salmon)	Wan et al. (1987)
8.8	LC50	mortality	acute (2 days)	*Oncorhynchus gorbuscha* (pink salmon)	Wan et al. (1987)
6.1	LC50	mortality	acute (3 days)	*Oncorhynchus gorbuscha* (pink salmon)	Wan et al. (1987)
5.3	LC50	mortality	acute (4 days)	*Oncorhynchus gorbuscha* (pink salmon)	Wan et al. (1987)
7.5	LC50	mortality	acute (4 days)	*Oncorhynchus gorbuscha* (pink salmon)	Wan et al. (1987)
9.7	LC50	mortality	acute (1 day)	*Oncorhynchus tshawytscha* (chinook salmon)	Wan et al. (1987)
9.7	LC50	mortality	acute (2 days)	*Oncorhynchus tshawytscha* (chinook salmon)	Wan et al. (1987)
9.7	LC50	mortality	acute (3 days)	*Oncorhynchus tshawytscha* (chinook salmon)	Wan et al. (1987)
9.7	LC50	mortality	acute (4 days)	*Oncorhynchus tshawytscha* (chinook salmon)	Wan et al. (1987)
9.9	LC50	mortality	acute (1 day)	*Oncorhynchus kisutch* (silver salmon)	Wan et al. (1987)
9.6	LC50	mortality	acute (2 days)	*Oncorhynchus kisutch* (silver salmon)	Wan et al. (1987)
9.6	LC50	mortality	acute (4 days)	*Oncorhynchus kisutch* (silver salmon)	Wan et al. (1987)
8.4	LC50	mortality	acute (1 day)	*Oncorhynchus mykiss* (rainbow trout)	Wan et al. (1987)
7.8	LC50	mortality	acute (2 days)	*Oncorhynchus mykiss* (rainbow trout)	Wan et al. (1987)
7.6	LC50	mortality	acute (3 days)	*Oncorhynchus mykiss* (rainbow trout)	Wan et al. (1987)
7.9	LC50	mortality	acute (1 day)	*Oncorhynchus nerka* (chum salmon)	Wan et al. (1987)
7.5	LC50	mortality	acute (2 days)	*Oncorhynchus nerka* (chum salmon)	Wan et al. (1987)
7.5	LC50	mortality	acute (3 days)	*Oncorhynchus nerka* (chum salmon)	Wan et al. (1987)
7.5	LC50	mortality	acute (4 days)	*Oncorhynchus nerka* (chum salmon)	Wan et al. (1987)

Toxicity (mg/L)	Measure	Endpoint	Acute/chronic	Species	Source of data
7.8	LC50	mortality	acute (1 day)	*Oncorhynchus keta* (sockeye salmon)	Wan et al. (1987)
7.5	LC50	mortality	acute (2 days)	*Oncorhynchus keta* (sockeye salmon)	Wan et al. (1987)
7.5	LC50	mortality	acute (3 days)	*Oncorhynchus keta* (sockeye salmon)	Wan et al. (1987)
7.5	LC50	mortality	acute (4 days)	*Oncorhynchus keta* (sockeye salmon)	Wan et al. (1987)
10	NOEC	growth	acute (5 days)	*Danio rerio* (Zebra Danio)	Stehr et al. (2009)

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Appendix C – metal speciation modelling

Metal concentrations and other input parameters

Speciation modelling (Visual MINTEQ, Version 3.0) was conducted for leachates generated from MWOO collected from each of the facilities during SE5. Due to the similarities in results, only the data from one facility (Facility B) are shown. Metal concentrations and other water quality parameters for the leachates are summarised in Table A16.

Table A16: Input parameters used for modelling metal speciation in Facility B MWOO leachates. All units mg/L unless otherwise stated

Parameter	Value	Notes
pH (units)	6.7	See below for additional pH values used
Temp (°C)	22	Modelling also done at 10°C showed only minor differences
Dissolved O_2	1.8	
Na	700	
K	1200	
Ca	790	
Mg	190	
Si	9	H_4SiO_4
Cl^-	1100	
SO_4^{2-}	590	
SO_3^{2-}	32	Calculated from difference between total sulfur and sulfate
S^{2-}	0.29	
NO_3^-	0.01	Nitrate concentration also manipulated to check charge balance (see below)
NH_3-N	440	
FRP	8	Filterable reactive phosphorus
DOC	6247	
Al	12	
As	0.11	
B	1.4	
Ba	0.18	
Cd	0.02	
Co	0.07	
Cr	0.12	
Cu	1.1	

Parameter	Value	Notes
Fe	17	
Hg (μg/L)	0.11	
Li	0.05	
Mn	4.8	
Mo	0.07	
Ni	0.5	
Pb	0.1	
Sb	0.02	
Sn	0.05	
Sr	2.9	
V	0.05	
Zn	7.2	

Dissolved organic carbon (DOC) and natural organic matter (NOM)

Organic modelling was performed using the NICA-Donnan database incorporated in Visual MINTEQ. The ratio between NOM concentrations and DOC was set at 1.65:1 according to the default value in MINTEQ. Modelling was performed assuming organic matter was 50% fulvic acids and 50% humic acids. The default values for binding site density were used, despite the fact that organic matter from the MWOO is unlikely to have the same characteristics as aged aquatic-derived NOM, for which the model has been validated. Using the default values was justified by the assumption that terrestrial-derived NOM (more comparable to the AWT leachates) is regarded as having a higher affinity for metals than aquatic-derived NOM (Richards et al. 2001). In other words, the default binding site parameters are likely to provide an overestimate of metal bioavailability.

Redox conditions

Reliable redox data were not available from this study, therefore, to investigate the influence of redox conditions on metal speciation, three different redox values were used:

- Eh = 0 mV (anoxic conditions)
- Eh = -200 mV (more extreme anoxic conditions)
- Eh = +400 mV (mildly oxic conditions).

Leachate pH

Modelling was conducted using the measured pH of the leachates (6.7). To investigate the effect of pH on speciation, two additional pH values were used:

- pH = 5.0 (more acidic)
- pH = 8.0 (slightly alkaline).

Mineral phases

Varying concentrations of hydrous ferric oxide (HFO) were used to simulate binding of metals to mineral phases. Three concentrations of HFO were used:

- 650 mg/L – used to simulate soil pore waters. This concentration was based on a total soil concentration of 250 mg HFO/kg, a soil porosity of 0.5 and bulk density of 1.3 g/cm^3. The HFO concentration is at the low end of concentrations expected for Australian agricultural soils. The bulk density was chosen as a value representative of both sandy and silty soils. The concentration 650 mg/L is the soil solution concentration when the soil is saturated.
- 1 mg/L – estimate of the HFO concentration in the F1 fraction column leachates. This was determined as the approximate difference between measured acid extractable and filterable iron concentrations in the leachates.
- 65 mg/L – used as an intermediate concentration.

Charge difference (balance)

Initial Visual MINTEQ modelling calculated a charge difference of approximately 20%, due to an excess of cations over anions. The charge difference is used as a quality control measure, and a charge difference of > 5% is generally regarded as unacceptable, as it could indicate a mistake in the concentrations of major components or the units used to enter them. The high charge imbalance in this case required further investigation.

A simple calculation of charge balance was made, based on the concentrations of major cations and anions but excluding the negative charges associated with NOM. This calculation produced a similar positive charge imbalance as calculated by Visual MINTEQ. When the negative charge associated with the binding sites on NOM were included in the calculation the charge balanced was reduced to within 1%. Therefore we suspect the excess of positive charge calculated by Visual MINTEQ is due to the extremely high concentration of NOM in the leachates.

The influence of the charge imbalance was checked using nitrate to balance the charge (to within 2.5%). Nitrate was chosen as it is not expected to greatly change the speciation of metals due to its poor affinity for metal binding. The difference in complexation of metals by NOM with and without nitrate was less than 0.5% for all metals. This suggests the high charge imbalance was not a key factor in controlling the metal speciation. On this basis, all further modelling was conducted without 'artificial' charge balancing (i.e. the measured concentrations of nitrate were used).

Results for full suite of metals

Speciation of redox sensitive metal

The effects of changing redox and pH on the oxidation state of the metals is shown in Table A17. The speciation of antimony and arsenic changed dramatically from 100% of the lower oxidation state (Sb(III) and As(III)) to the 100% of the higher oxidation state (Sb(V) and As(V)) as conditions changed from low to high Eh and pH. This is consistent with expected redox behaviour of these metalloids.

Vanadium speciation was dominated under all modelled conditions by V(IV). This is counter to general observations that V(V) dominates in environmental samples (ANZECC & ARMCANZ 2000). In this case, it is likely that the high concentration of NOM is stabilising the cationic (positively charged) V(IV) species (VO^{2+}), making the anionic (negatively charged) V(V) species (HVO_4^{2-}) less favoured. Similarly the finding of low Fe(II) concentrations, even at very low Eh values, is likely a consequence of stabilisation of the trivalent Fe(III) species by NOM.

Under the range of conditions modelled, Co(III), Cr(VI), Fe(II), Mn(III), Sn(II) and V(III) were present at very low proportions. Based on this, these species were excluded from further modelling.

Table A17: Modelled percentage of redox states for redox sensitive metals under varying redox and pH conditions. Values are shown as a percent of total metal occurring in an individual redox state. Eh values are in mV

Metal	Redox state	pH = 6.7			Eh = 0		
		Eh = -200	Eh = 0	Eh = +400	pH = 5.0	pH = 6.7	pH = 8.0
Antimony	Sb(III)	100.0	100.0	<0.1	100.0	100.0	61.3
	Sb(V)	<0.1	<0.1	100.0	<0.1	<0.1	38.9
Arsenic	As(III)	100.0	88.5	<0.1	100.0	88.5	<0.1
	As(V)	<0.1	11.5	100.0	<0.1	11.5	100.0
Cobalt	Co(II)	100.0	100.0	100.0	100.0	100.0	100.0

Metal	Redox state	pH = 6.7			Eh = 0		
		Eh = -200	Eh = 0	Eh = +400	pH = 5.0	pH = 6.7	pH = 8.0
	Co(III)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Chromium	Cr(III)	100.0	100.0	100.0	100.0	100.0	100.0
	Cr(VI)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Iron	Fe(II)	1.5	0.1	<0.1	5.9	0.1	<0.1
	Fe(III)	98.5	99.9	100.0	94.1	99.9	100.0
Manganese	Mn(II)	100.0	100.0	100.0	100.0	100.0	100.0
	Mn(III)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Tin	Sn(II)	6.1	<0.1	<0.1	6.0	<0.1	<0.1
	Sn(IV)	93.9	100.0	100.0	94.0	100.0	100.0
Vanadium	V(III)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
	V(IV)	100.0	100.0	92.4	100.0	100.0	100.0
	V(V)	<0.1	<0.1	7.6	<0.1	<0.1	<0.1

Metal complexation and adsorption

The modelled proportions of adsorbed (to NOM or HFO) and dissolved species at the three HFO concentrations are shown in Table A18. Note that Visual MINTEQ does not have appropriate constants in the default database for NOM interactions with tin, therefore, this data have been included only to determine the possible distribution between Sn(II) and Sn(IV) species, and any mineral adsorption.

The modelling suggests that complexation by NOM heavily dominates (> 95 – 100 %) the speciation of aluminium, cadmium, cobalt, chromium, iron, mercury, manganese, nickel, lead, vanadium and zinc. This result is in keeping with the extremely high concentration of NOM in the leachate (> 6 g/L DOC). Ba and Sr are also partially associated with NOM (> 70 %).

Adsorption to HFO was only significant for arsenate (AsO_4^{3-}), arsenite ($HAsO_3$), and $Sn(OH)_2$ and generally only at high concentrations of HFO. Adsorption of these species is a consequence of the fact that HFO has surface sites with either positive or negative charges, the former of which are capable of binding metals that exist as negatively charged oxyanion species.

In the low HFO scenario (1 mg/L), modelling indicated that a significant proportion of dissolved inorganic metal (> 1 %) could occur for arsenic (as arsenate and arsenite), boron (as boric acid), barium, cobalt, lithium, manganese, molybdenum (as molybdate), nickel, antimony, tin, strontium, vanadium (as vanadate), and zinc. In contrast, in the high HFO scenario, simulating soil porewater (650 mg/L HFO), the proportion of nickel and zinc is reduced to below 1 % by adsorption to HFO.

Table A18: Modelled organic complexation and mineral adsorption at Eh = 0 mV and pH = 6.7 for the full suite of metals in the leachates

Metal species	Modelled as soil with 650 mg/L HFO				Modelled as soil with 65 mg/L HFO				Modelled as leachate with 1 mg/L HFO			
	‘Total’ µg/L	Organic %	Mineral surfaces %	Dissolved inorganic %	‘Total’ µg/L	Organic %	Mineral surfaces %	Dissolved inorganic %	‘Total’ µg/L	Organic %	Mineral surfaces %	Dissolved inorganic %
Al	12000	100.0	0.0	0.0	12000	100.0	0.0	0.0	12000.0	100.0	0.0	0.0
H_3AsO_3	11.1	0.0	79.7	20.3	83.4	0.0	12.4	87.6	97.1	0.0	0.2	99.8
AsO_4^{-3}	1.4	0.0	97.4	2.6	10.9	0.0	26.5	73.5	12.6	0.0	0.4	99.6
H_3BO_3	1400	1.2	0.0	98.7	1400	1.2	0.0	98.8	1400.0	1.2	0.0	98.8
Ba	179.1	71.8	0.5	27.8	179.9	71.8	0.0	28.2	180.0	71.8	0.0	28.2
Cd	20.0	100.0	0.0	0.0	20.0	100.0	0.0	0.0	20.0	100.0	0.0	0.0
Co(II)	69.8	96.2	0.3	3.5	70.0	96.1	0.0	3.8	70.0	96.1	0.0	3.9
Cr(III)	120.0	100.0	0.0	0.0	120.0	100.0	0.0	0.0	120.0	100.0	0.0	0.0
Cu	1100	100.0	0.0	0.0	1100	100.0	0.0	0.0	1100.0	100.0	0.0	0.0
Fe(II)	24.7	100.0	0.0	0.0	24.7	100.0	0.0	0.0	25.0	100.0	0.0	0.0
Fe(III)	16978	100.0	0.0	0.0	16978	100.0	0.0	0.0	16978.0	100.0	0.0	0.0
Hg	0.1	100.0	0.0	0.0	0.1	100.0	0.0	0.0	0.1	100.0	0.0	0.0
Li	50.0	12.3	0.0	87.7	50.0	12.3	0.0	87.7	50.0	12.3	0.0	87.7
Mn(II)	4789	96.1	0.2	3.7	4799	96.1	0.0	3.9	4800.0	96.0	0.0	4.0
MoO_4^{-2}	59.3	0.0	15.3	84.7	69.5	0.0	0.7	99.3	70.0	0.0	0.0	100.0
Ni	498.3	98.9	0.3	0.8	499.7	98.9	0.0	1.1	500.0	98.9	0.0	1.1
Pb	99.2	99.2	0.8	0.0	100.0	100.0	0.0	0.0	100.0	100.0	0.0	0.0
$Sb(OH)_3$	20.0	0.0	0.0	100.0	20.0	0.0	0.0	100.0	20.0	0.0	0.0	100.0
$Sb(OH)_6^{-1}$	0.0	0.0	0.1	99.9	0.0	0.0	0.0	100.0	0.0	0.0	0.0	100.0
$Sn(OH)_2$	0.0	0.0	99.4	0.6	0.0	0.0	95.0	5.0	0.0	0.0	21.8	78.2

Metal species	Modelled as soil with 650 mg/L HFO				Modelled as soil with 65 mg/L HFO				Modelled as leachate with 1 mg/L HFO			
	‘Total’ µg/L	Organic %	Mineral surfaces %	Dissolved inorganic %	‘Total’ µg/L	Organic %	Mineral surfaces %	Dissolved inorganic %	‘Total’ µg/L	Organic %	Mineral surfaces %	Dissolved inorganic %
$Sn(OH)_6^{-2}$	50.0	0.0	0.0	100.0	50.0	0.0	0.0	100.0	50.0	0.0	0.0	100.0
Sr	2896	71.9	0.2	28.0	2900	71.8	0.0	28.1	2900.0	71.8	0.0	28.2
VO^{+2}	50.0	100.0	0.0	0.0	50.0	100.0	0.0	0.0	50.0	100.0	0.0	0.0
HVO_4^{-2}	0.0	0.0	0.2	99.8	0.0	0.0	0.0	100.0	0.0	0.0	0.0	100.0
Zn	7037	97.7	2.3	0.0	7186	98.4	0.2	1.4	7201.0	98.4	0.0	1.6

Effect of varying redox and pH on speciation

Table A19 summarises the calculated dissolved inorganic metal concentrations for three different values of Eh (at constant pH) and three different values of pH (at constant Eh). Concentrations have been shown as opposed to percentages (of each total species) because the percentages of dissolved inorganic metal are, in some cases, too low to show any meaningful trend.

The speciation of chromium, copper iron and mercury are unaffected by changes in either Eh or pH, as a consequence of strong association with NOM. Dissolved inorganic concentrations of barium and strontium are unaffected by changes in Eh (redox potential) but decrease with increasing pH. This is a consequence of lower competition for binding sites from H^+ at higher pH values.

For arsenic and antimony, the higher oxidation state becomes more stable under conditions of higher Eh and pH (as shown previously). This suggests that as MWOO material ages and organic matter is oxidised, these metalloids are likely to favour the higher oxidation state. In the case of arsenic, the higher oxidation state is known to be less mobile and less bioavailable. The geochemistry of antimony is less well known, and the effect on its longer-term bioavailability is harder to predict.

The concentrations of aluminium show an increase at both high and low pH. This is consistent with increased competition for NOM binding sites from H^+ at lower pH and the formation of soluble aluminium hydroxide species at higher pH. Both of those trends would result in an increase in bioavailable Al, but this would be especially relevant for low pH conditions.

The metals cadmium, cobalt, manganese, nickel, lead and zinc generally had lower dissolved inorganic concentrations under reducing redox conditions and at higher pH. The effect of pH can be explained by increased competition for NOM binding sites from H^+ at lower pH (as for aluminium). The effect of decreasing redox potential is better explained by the formation of soluble metal sulfide complexes, as indicated by the Visual MINTEQ modelling (data not shown). These metal sulfide complexes are likely to show low bioavailability to aquatic organisms. Therefore, the changes that occur in the speciation of these metals at low pH are likely to have little consequence on the overall bioavailability (and hence toxicity) of these metals.

Table A19: Concentrations of dissolved inorganic metal in leachate (µg/L) modelled under different redox and pH conditions. Eh values are in mV

Metal species	pH 6.7			Eh = 0		
	Eh = -200	Eh = 0	Eh = +400	pH = 5.0	pH = 6.7	pH = 8.0
Al	0.1	0.1	0.1	4.8	0.1	12.3
H3AsO3	110.0	96.8	0.0	110.0	96.8	0.0
AsO4-3	0.0	12.9	109.5	0.0	12.9	109.8
Ba	50.8	50.8	50.8	76.1	50.8	34.3
Cd	20.0	0.0	0.0	0.1	0.0	0.0
Co(II)	45.4	2.6	2.7	5.9	2.6	1.4
Cr(III)	0.0	0.0	0.0	0.0	0.0	0.0
Cu	0.0	0.0	0.0	0.0	0.0	0.0
Fe(II)	0.0	0.0	0.0	0.0	0.0	0.0
Fe(III)	0.0	0.0	0.0	0.0	0.0	0.0
Hg	0.0	0.0	0.0	0.0	0.0	0.0
Mn(II)	3178.9	181.4	190.1	502.0	181.4	171.3
Ni	220.7	5.1	5.4	11.5	5.1	3.0
Pb	99.5	0.0	0.0	0.0	0.0	0.0
Sb(OH)3	20.0	20.0	0.0	20.0	20.0	12.2
Sb(V)	0.0	0.0	20.0	0.0	0.0	7.8
Sr	805.6	808.5	816.4	1190.3	808.5	623.4
Zn	6088.6	113.1	116.0	474.2	113.1	15.3

Comparison with WHAM7 modelling

The reliability of the modelling of organic complexation by NOM was made by performing similar calculations using WHAM7 and comparing the results with those obtained from Visual MINTEQ (Table A20). WHAM7 is an equilibrium metal speciation software package available from the NERC Centre for Ecology & Hydrology, UK. It is designed to estimate solution metal speciation and surface complexation in (oxic) surface waters.

Differences in organic complexation calculated by the two models agreed to within 10 % for all metals except for cobalt and lead. The constants used for modelling cobalt complexation by organic matter are controversial. Empirical data suggest that NOM complexation in soil porewater is greater than is typically calculated in speciation models (Collins et al. 2010). Therefore the high complexation value calculated by Visual MINTEQ may be the more reliable of the two values. Similarly, Gustafsson et al. (2011) observed that lead dissolution from solid organic matter is often overestimated by modelling approaches. Again, this suggests that the greater lead complexation calculated by Visual MINTEQ may be more reliable.

Table A20: Organic (NOM) complexation as modelled by two different speciation programs (Visual MINTEQ and WHAM7). 'Difference' is the percentage by which WHAM7 differed from Visual MINTEQ

	Visual MINTEQ %	WHAM7 %	Difference %
Al	100.0	97.2	2.8
Cd	100.0	92.5	7.5
Co	96.1	41.5	56.8
CrIII	100.0	99.4	0.6
Cu	100.0	99.6	0.4
Fe(III)	100.0	96.2	3.8
Hg	100.0	100.0	0.0
Mn	96.0	97.5	-1.6
Ni	98.9	94.8	4.2
Pb	100.0	77.1	22.9
Zn	98.4	98.0	0.4

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