Environment Protection Authority

NSW Biosolids Regulatory Review

Technical Findings Report

Cover: Biosolids dropping from a conveyor, Orange; Photo: Hugh Brennan/EPA

Published by:

NSW Environment Protection Authority
6 Parramatta Square
10 Darcy Street, Parramatta NSW 2150
Locked Bag 5022, Parramatta NSW 2124

Phone: +61 2 9995 5000 (switchboard)
Phone: 131 555 (NSW only – environment information and publications requests)
Fax: +61 2 9995 5999
TTY users: phone 133 677, then ask
for 131 555
Speak and listen users:
phone 1300 555 727, then ask for 131 555

Email: info@epa.nsw.gov.au
Website: www.epa.nsw.gov.au

Report pollution and environmental incidents
Environment Line: 131 555 (NSW only) or info@epa.nsw.gov.au
See also www.epa.nsw.gov.au

ISBN 978 1 922963 24 6
EPA 2023P4443
July 2023

Contents

Acronyms

BHC	benzene hexachloride
CLBAR	Contaminant Limiting Biosolids Application Rate
DALY	disability Adjusted Life Year
DDD	dichlorodiphenyldichloroethane
DDE	dichlorodiphenyldichloroethylene
DDT	dichlorodiphenyltrichloroethane
DEHA	di-2-ethylhexyl adipate
DEHP	di-2-ethylhexyl phthalate
DPE	Department of Planning and Environment
DPI	Department of Primary Industries
ERA	Ecological Risk Assessment
HACCP	Hazard Analysis Critical Control Point
HEPA	Heads of EPA Australia and New Zealand
HCB	hexachlorobenzene
HHCB	Galaxolide
HHRA	Human Health Risk Assessment
HHERA	Human Health and Ecological Risk Assessment
MASCC	Maximum Allowable Soil Contaminant Concentration
NEMP	National Environmental Management Plan
NLBAR	Nitrogen Limiting Biosolids Application Rate
NSW EPA	NSW Environment Protection Authority
PBDEs	polybrominated diphenyl ethers
PCBs	polychlorinated biphenyls
PFAS	per-and poly-fluoroalkyl substances
PFHxS	perfluorohexane sulfonate
PFOA	perfluorooctanoic acid
PFOS	perfluorooctane sulfonate
POP	persistent organic pollutant
QMRA	Quantitative Microbial Risk Assessment
RQ_{ECO}	ecological risk quotient
RQ_{HH}	human health risk quotient
STPs	sewage treatment plants

Context

1.1. Resource Recovery Framework

The resource recovery framework is the policy, regulatory and compliance framework administered by the EPA to facilitate beneficial resource recovery and circular economy outcomes. The framework aims to divert waste from landfill and to minimise the risks to human health and the environment.

Applying biosolids and materials containing biosolids to land as a soil amendment is enabled by the resource recovery framework. Biosolids must provide a benefit to the soil, while at the same time pose minimal risk of harm to human health and the environment. This is governed by the *Environmental Guidelines: Use and Disposal of Biosolids Products* (the Biosolids Guidelines). The Biosolids Guidelines prescribe the requirements for applying biosolids products to land, including threshold limits for contaminants and stabilisation requirements to manage pathogens. The Biosolids Guidelines were published in 1997, before the Resource Recovery Framework. *The biosolids exemption 2014* provides exemptions from certain legislative provisions for biosolids that are applied to land or intended to be applied to land. *The biosolids order 2014* imposes requirements on the suppliers and generators of those biosolids. Both the order and exemption require the conditions of the Biosolids Guidelines to be met.

1.2. Review objectives

Since the Biosolids Guidelines were released, research on the risks associated with the land application of biosolids has continued. Knowledge and experience in biosolids management by both industry and regulators have also increased and changes in waste legislation has also occurred. The EPA committed to reviewing the Biosolids Guidelines to make sure regulatory settings are protective, practical, and clear.

This aligns with the EPA's commitment in our Strategic Plan to prioritise actions to cut the impact of waste and contaminants on the environment under the focus areas of Waste and Legacy and Emerging Contaminants. It also supports the EPA's commitments under the *NSW Government's Waste and Sustainable Materials Strategy 2041*.

1.3. This report

This report presents the findings from each major part of the review to date and the future focus:

i. definition of biosolids
ii. the licensee survey
iii. grading and classification
iv. chemical contaminants
v. pathogens
vi. stability and odour management
vii. management controls.

It gives stakeholders the opportunity to consider the current state of understanding, and provides detailed information, including methods and assumptions, underlying the technical studies and findings.

What are biosolids?

Biosolids and the Biosolids Guidelines are currently defined for the purposes of Schedule 1 to the *Protection of the Environment Operations Act 1997* (the Act) as follows.

> ***biosolids*** means the organic product that results from sewage treatment processes (sometimes referred to as sewage sludge).
>
> ***Biosolids Guidelines*** means the document entitled *Environmental Guidelines: Use and Disposal of Biosolids Products*, published by the EPA and as in force from time to time, copies of which are held in the offices of the EPA.
>
> **Note —** A copy of the guidelines is available on the EPA's website (www.epa.nsw.gov.au).

The current definition of biosolids includes sewage sludge. However in a technical sense, sewage sludge is what remains when most of the liquid component of influent to a sewage treatment plant (STP) is removed. The sludge remains highly pathogenic, unstable, odorous, contaminated, and unsuitable for beneficial reuse. It needs further treatment to produce biosolids. The guidelines for most other Australian jurisdictions (NT, SA, WA, Tas, Vic) draw a distinction between sewage sludges and biosolids. The distinction is also made by the sewage treatment industry in NSW. The Australia & New Zealand Biosolids Partnership defines biosolids as:

> "*a product of the sewage sludge once it has undergone further treatment to reduce disease causing pathogens and volatile organic matter significantly, producing a stabilised product suitable for beneficial use.*"[1]

The EPA is considering changing the definition of biosolids. A clear definition is also important in relation to energy recovery from the thermal treatment of waste. Biosolids are exempt from the provisions in Chapter 9 Part 4 of the Protection of the Environment Operations (General) Regulation 2022 (the Regulation). Water utilities would like to ensure that they are able to thermally treat sewage sludge or partially treated sludge in the future. The implications of any potential change in the definition of biosolids will need to be considered with respect to the regulation of energy from waste.

1 https://www.biosolids.com.au/wp-content/uploads/What-are-biosolids.pdf

EPA licensee survey

In 2021-22, the EPA completed a survey of sewage treatment plant (STP) licensees to assess the state of biosolids production in NSW in 2020. A summary of the survey results is provided in Figure 1. Of the 277 responses relating to 255 environment protection licences, 220 produced biosolids.

Biosolids were produced by a broad range of sewage treatment plant processes and capacities. STPs processing waste from under 50,000 people accounted for 40% of biosolids produced in 2020. Most biosolids were classified as *Restricted Use 2*, with only one producer potentially being *Restricted Use 1*. The survey indicated that trade waste is an important part of biosolids production with 60% of responses having a current trade waste agreement with a broad list of industries represented. Sewage treatment capabilities are generally very good in NSW, with 70% of responses choosing a tertiary level wastewater treatment facility.

The survey was seeking information on the end uses and classification of biosolids in NSW, determined by limiting contaminants and stabilisation techniques. The main end use was 'supplied to an external party to be directly land applied.' About half of all responses chose 'agriculture' as the beneficial end use industry, followed by a mix of non-beneficial uses (including stockpiling onsite and landfill). There were many limiting contaminants chosen, but the most common were copper, zinc and selenium, often in combination.

Stabilisation methods were mainly dewatering, lagoon storage and extended aeration. The survey showed a lack of data and/or record keeping, with inconsistent responses suggesting that some licensees don't know their responsibilities under the Biosolids Guidelines.

The survey highlighted the many variations in biosolids production in NSW – including sewage treatment processes, different trade waste inputs, combinations of chemical contaminants, combinations of stabilisation techniques and a number of end-uses. Any revision of the Biosolids Guidelines should clearly show the sampling and classification responsibilities of the different parties involved.

The EPA has used GIS mapping to correlate this information for all water catchments within NSW.

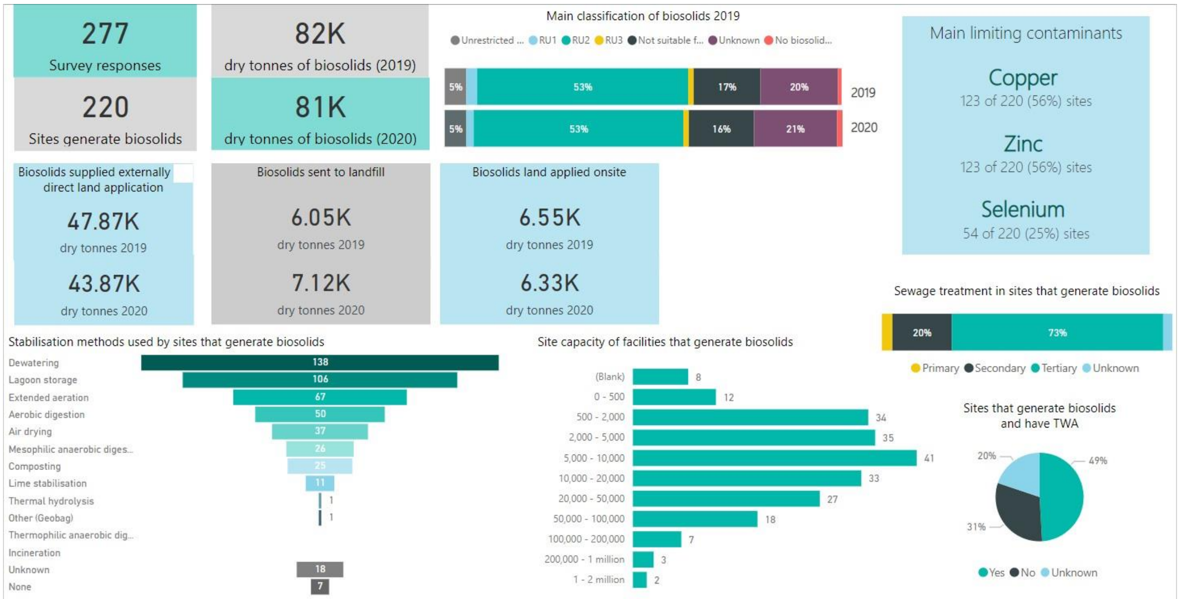

Figure 1 Summary of key findings from the licensee survey

Classification and sampling

The regulatory review aims to improve the clarity of requirements for producers, processors and consumers of biosolids. The classification requirements were reviewed, and a simplified system is being proposed that reflects modern-day contaminants, their concentrations in biosolids and how well they are stabilised.

4.1. Current requirements

Classification for biosolids is a combination of the contaminant and stabilisation grades.

Contaminant grading

Contaminant grading requires analysis of a representative number of samples for a prescribed suite of chemical contaminants including heavy metals, pesticides and polychlorinated biphenyls. Results allow a contaminant grade to be established from A (lowest concentrations) to E (highest concentrations).

Stabilisation grading

The stabilisation grade is determined by the type and degree of treatment that biosolids undergo to reduce microbial pathogens, and vector attractants (flies and vermin). The treatment process should also stabilise the biosolids by irreversibly changing the organic matter so that biological activity is low, and odours are reduced. The highest stabilisation grade also needs analysis of microbial agents in the final biosolids to meet specified levels. The stabilisation grade is based on the treatment effectiveness and ranges from A (most effective) to C (least effective).

The contaminant and stabilisation grades combine to produce five classifications for biosolids ranging from 'Unrestricted use' (highest quality biosolids) to 'Not suitable for use' (needing reprocessing or disposal) shown in Table 1. While 'Unrestricted use' implies any quantity of biosolids can be applied without restriction in perpetuity, in practice application to land is always restricted to stay below Maximum Allowable Soil Contaminant Concentration (MASCC) thresholds in the Biosolids Guidelines. There are two MASCC values for each contaminant depending on whether the biosolids are applied to agricultural land (Table 4-5 of the Biosolids Guidelines) or non-agricultural land (Table 4-13 of the Biosolids Guidelines).

Table 1 Current biosolids classification system

Classification	Contaminant Grading (minimum)	Stabilisation Grading (minimum)	End use option
Unrestricted Use	A	A	all
Restricted Use 1	B	A	2-9
Restricted Use 2	C	B	4-9
Restricted Use 3	D	B	6-9
Not Suitable For Use	E	C	7-9

Each classification determines allowed end-use options, with more restrictions as biosolids quality decreases.

1. home lawns and gardens
2. public contact sites (eg recreational parks)
3. urban landscaping (eg council land)
4. agriculture
5. forestry
6. soil and site rehabilitation (eg abandoned mines)
7. surface land disposal (eg within the licensed STP premises)
8. reprocessing (e.g. composting)
9. landfill disposal.

4.2. Proposed requirements

To simplify the process, the EPA is considering cutting the number of contaminant grades from five (A-E) to two (C1 or C2).

The number of stabilisation grades are also proposed to be reduced from three (A-C) to two and new terminology used to reflect the changes where S1 (most effective) and S2 (less effective) replaces A and B, respectively.

Class I biosolids combines and replaces 'Unrestricted Use' and 'Restricted Use 1'. Class II replaces 'Restricted Use 2'. Class III combines and replaces 'Restricted Use 3' and 'Not Suitable for Use'. Tables 2 and 3 show these changes.

Table 2 Simplified classification for biosolids

New classification	Current classification
Class 1	Unrestricted Use Restricted Use 1
Class II	Restricted Use 2
Class III	Restricted Use 3 & Not Suitable For Use

Table 3 New classifications for contaminant and stabilisation grades with allowed end-use options

New classification	Contaminant grading	Stabilisation grading	End-use option
Class 1	C1	S1	all
	C1	S2	2 to 9
Class II	C2	S1	3 to 9
	C2	S2	-
Class III	C1 or C2	ungraded	8 to 9
	ungraded	S1 or S2	-
	ungraded/failed C2	ungraded/failed S2	-

Class I biosolids with an S1 grade will be suitable for direct land application in all end-uses including those where humans are regularly in close contact with the application site.

Class II biosolids can be used for application in agriculture provided other parts of the Biosolids Guidelines are followed correctly (eg, best practice land management, to be protective of human health and the environment). Most biosolids produced in NSW will likely fall in this category.

Class III will be for biosolids that have not met contaminant and/or stabilisation thresholds suitable for land application. Options include disposal or further processing and reclassification as Class I or Class II before land application. Stockpiling low quality biosolids or applying them on licensed premises is not good for the environment, especially in water catchment areas that are subject to flooding. This practice should be reviewed by STP operators and the EPA on a case-by-case basis.

4.3. Pre-classification of biosolids for disposal to landfill

In NSW, all solid waste disposed to landfill must be classified using the EPA's *Waste Classification Guidelines Part 1: Classifying waste* (Waste Guidelines). The waste guidelines list chemicals considered environmentally harmful and provide criteria that classifies the contaminants present based on the likelihood of leachability and potential for environmental risk. The waste guidelines also pre-classify certain wastes that need no further chemical assessment. Biosolids are currently pre-classified general solid waste (putrescible). However, chemical contaminants that pose environmental risk have been identified in biosolids at problematic concentrations both in Australia and globally.

Monitoring for these contaminants in biosolids is needed to understand whether they exceed general solid waste thresholds. This will be achieved through the EPA's Biosolids Sampling Project – which happened from March to May 2023 at 75 different STPs around NSW. Biosolids have low immobilising characteristics and the potential for contaminant leaching is high.

The EPA will review the suitability of the waste guidelines pre-classification based on data under the biosolids sampling project and data provided by STP operators.

4.4. Sampling

The EPA is considering sampling requirements following a review of the stabilisation and contaminant grading and classification framework. A statistician is determining the basis for sampling using several approaches designed to minimise the needs for biosolids producers while making sure sampling is suitable for the protection of human health and the environment. It is intended that this work will be finished once the regulatory approach has been established.

Chemical Contaminants

5.1. Review of contaminants

In 2016, the EPA commissioned a literature review on contaminants of concern in biosolids applied to land and the associated risks to agriculture, human health and the environment. The review was titled *Environmental Guidelines: Use and Disposal of Biosolids Products – Contaminant Review* (the Contaminants Review) and is available on the EPA website.

The aims of the Contaminants Review were to identify which chemical contaminants of concern have relevance to NSW biosolids using existing available data from sewage treatment plants (STPs), published research, and policies and guidelines from local and international jurisdictions. Consideration was also given to whether any chemicals in NSW biosolids no longer needed to be regulated as they are no longer a risk to the environment or human health. The strategy used for contaminant selection and prioritisation followed a 3-step process:

(i) likely to be in biosolids based on literature and existing data;

(ii) persistence of the chemical in soil based on physicochemical properties; and

(iii) potential risk to the environment or human food chain based on toxicity and likely exposure.

A short list of potential contaminants of concern was prioritised for routine measurement in NSW biosolids.

The Contaminant Review identified 158 chemicals of concern from which a representative group of 42 chemicals (24 organic compounds and 18 metals) was selected for further assessment. A risk characterisation ratio for environmental risk was determined by comparing the predicted environmental concentration to a terrestrial predicted no effect concentrations. A ratio>1 indicates a potential risk. For human health, a ranking was given using measures of toxicological potency such as acceptable daily intake or reference dose. The chemicals were further refined into four categories:

(i) those prioritised for monitoring;

(ii) those needing further consideration to determine inclusion or removal for monitoring as one aspect of their assessment was not matched to Australian data;

(iii) those chemicals for which one part of the assessment was not possible so they are “parked” until further information is available; and

(iv) chemicals presenting a low risk under the assumptions used.

The Contaminant Review concluded that for many of the chemicals measured in biosolids globally there is little, if any, data for NSW biosolids and that a broad assessment of chemicals was needed. The EPA treated this conclusion as important, given the large amount of biosolids that’s applied to land in NSW.

Some chemicals were highlighted for future routine monitoring in NSW with the highest priority given to triclosan and HHCB (Galaxolide).

Other chemicals that should be given further consideration and local assessment include PFOS and then benzo(a)pyrene, Cashmeran, decamethylcyclopentasiloxane, DEHP, HBCD, PFOA and Tonalide.

Some chemicals were identified as being relevant for long-term monitoring because of likely persistence in amended soils. However, there wasn’t enough existing data to draw conclusions and so these chemicals were “parked” until further data is available. Microplastics and precious metals were also identified as being relevant because of persistence in amended soils.

Of the chemical contaminants currently regulated it was recommended that continual monitoring was not needed for lead, nickel, cobalt, molybdenum, lindane, BHC, aldrin, heptachlor, DDD, DDE and DDT. Occasional monitoring for cadmium and chromium was recommended to provide clear evidence for inclusion or removal.

Table 4 Chemicals prioritised for monitoring based on evidence in the 2016 WCA Contaminants Review.

*Indicates high or very high human health hazard score. **Chemicals selected for testing in 2017 EPA sampling campaign (+ BDE-209) are shown in bold**.

Prioritised	For further consideration	'Parked'	Low environmental risk
1. Copper 2. Zinc 3. Dieldrin* 4. **HHCB (Galaxolide)** 5. **Triclosan**	6. Cadmium* 7. Chromium 8. **PFOS*** 9. **Benzo(a)pyrene*** 10. **Cashmeran** 11. **Decamethylcyclopenta siloxane** 12. **DEHP** 13. **HBCD** 14. **PFOA** 15. **Tonalide** Based on toxicological potency alone: 16. **Alpha-chlordane*** 17. Arsenic* 18. **Diclofenac*** 19. **BDE-47***	20. Silver 21. Barium 22. Beryllium 23. Vanadium. 24. Titanium 25. Manganese 26. Selenium 27. Mercury 28. 1,2-bis(2,4,6-Tribromophenoxy) ethane (BTBPE), 29. di(2-ethylhexyl)-2,3,4,5-tetrabromophthalate (TBPH), Hexabromobenzene (HBB), 30. Perfluorodecanoate 31. PCDD/DFs & dioxin-like PCBs* 32. PFNA 33. Triclocarban 34. Precious metals (Pt, Pd, etc.) 35. Microplastics	36. Decabromodiphenyl ethane (DBDPE) 37. Dodecamethylcyclohexa siloxane 38. Dichlorodiphenyl dichloroethane (DDD) 39. Dichlorodiphenyl dichloroethylene (DDE) 40. Antimony 41. Cobalt 42. Lead 43. Molybdenum 44. Nickel

5.2. Sampling campaign

In response to the Contaminants Review, the EPA carried out a state-wide sampling event of biosolids from 20 NSW STPs in May 2017, at both rural and urban locations. Twelve emerging contaminants (shaded in Table 4) that are not currently included in the Biosolids Guidelines were analysed (including per- and polyfluoroalkyl substances (PFAS)). The EPA collaborated with the (now) Department of Planning and Environment (DPE) to prioritise five contaminants (PFAS, polybrominated diphenyl ethers (PBDEs), triclosan, HHCB (Galaxolide) and chlordane) for further investigation due to potential ecological and human health risks.

DPE also undertook Human Health and/or Ecological Risk Assessments (HHERAs) for these contaminants in NSW biosolids for the EPA. The aim was to determine if regulation was needed and if so, derive limits for revised guidelines.

PFAS National Environmental Management Plan (NEMP) version 3.0

The PFAS NEMP version 2.0 sets up a practical basis for nationally consistent environmental guidance and standards for managing PFAS contamination. The EPA's HHERA for PFAS and the methodology for deriving limits was shared with the National Chemicals Working Group as part of the development of the PFAS NEMP 3.0. The EPA co-led workshops for the National Chemicals Working Group in October 2020 to support jurisdictions in setting up risk-based approaches for managing PFAS in biosolids. The aim was to develop nationally consistent guidance. Assumptions on which the HHERA is based were agreed with the NSW Biosolids Regulatory Committee before this in May 2019. Finalisation of the EPA's HHERA for PFAS was put on hold while NEMP 3.0 was developed.

The Draft NEMP 3.0 was updated by the National Chemicals Working Group, under the Heads of EPAs Australia and New Zealand, and was released for public consultation on 23 September 2022 for 12 weeks. The Draft NEMP 3.0 criteria for PFAS compounds in biosolids are based on the outcomes of the EPA HHERA. The criteria for PFAS compounds PFOS+PFHxS are the same as the EPA's criteria. The Draft NEMP 3.0 criterion for the PFAS compound PFOA is half the limit proposed by the EPA. The difference in the PFOA criterion came about because of differing ecological criteria that was then developed for the Draft NEMP 3.0. The Draft NEMP 3.0 value was derived using Canadian ecotoxicology data while the EPA value used data from the UK. The EPA intends to update its proposed criteria to align with the NEMP 3.0 once it is published.

5.3. PFAS Human Health and/or Ecological Risk Assessments (HHERA)

The aim of this HHERA[2] was to determine if PFAS in biosolids need regulation and to identify the key exposure pathways for PFAS in biosolids for deriving thresholds. The scope was to:

1. review PFAS data collected from 20 STPs in NSW and compare these to data used in the Contaminants Review to see if concentrations in NSW are consistent with concentrations reported around the world.
2. undertake a HHERA for PFAS in NSW biosolids considering these scenarios
    - Scenario 1 – land application of 'unrestricted use[3]' biosolids in residential gardens
    - Scenario 2 – land application of 'unrestricted use' biosolids for land rehabilitation (assumes land will not be used for agriculture in the future)
    - Scenario 3 – land application of 'restricted use' biosolids in agriculture (includes rehabilitated land that will be used for agriculture in the future) considering:
        - a low and high application rate and
        - single and repeat applications
    - Scenario 4 – land application of 'unrestricted use' biosolids in agriculture.
3. use the results from the HHERA to determine whether PFAS in biosolids should be regulated and to identify the key exposure pathways for deriving biosolids thresholds for PFAS
4. recommend next steps and any extra work to address knowledge gaps.

---

2 NSW Department of Planning and Environment, Environment and Heritage Group 2023. *NSW Biosolids Guideline Review: Identification of key exposure pathways to assess risks from PFAS in biosolids.* (Available on the EPA website.)

3 As defined in the Biosolids Guidelines.

The data was drawn from the 2017 EPA biosolids sampling campaign. While many PFAS compounds were analysed and detected in the biosolids samples, the HHERA focused on three compounds only, PFOS, PFOA and perfluorohexane sulfonate (PFHxS). This was because these are the only ones currently with criteria available in Australia that can be measured. On average, the concentrations of PFOS, PFOA and PFHxS made up 60% of the total PFAS concentration.

These congeners of PFAS have been used widely in NSW as flame retardants in firefighting foams as well as the manufacture of non-stick materials. PFAS has been getting more and more global attention because it's persistent and bioaccumulative in the environment.

PFOS was detected in all biosolids samples, with concentrations ranging from 3.2 to 77 µg/kg. This maximum concentration was about 1.7 times lower than the 90^{th} percentile concentration reported in studies around the world in the Contaminants Review (130 µg/kg). For PFOA, the concentrations ranged from <2.7 to 24 µg/kg, with the maximum concentration about 1.7 times higher than the 90^{th} percentile concentration reported in the Contaminants Review (14 µg/kg). These results for PFOS and PFOA show that concentrations in NSW biosolids are in a similar range to concentrations reported around the world. The concentrations of PFHxS were lower than PFOS and PFOA, ranging from <0.1 to 3.8 µg/kg. This compound was not included in the Contaminants Review so couldn't be compared.

5.3.1. Risk assessment methodology

Exposure concentrations or exposure doses of PFOS, PFOA and PFHxS were calculated in biosolids-amended soil, agricultural produce (crops, beef, milk) and drinking or irrigation water using NSW biosolids data.

Ecological risks were assessed for PFOS and PFOA by calculating an ecological risk quotient (RQ_{ECO}), by dividing the estimated biosolids-amended soil concentrations by relevant screening criteria. In most cases, the soil screening criteria used were from the PFAS NEMP 2.0. However for PFOA, the screening criterion from the United Kingdom (UK) adjusted to Australian conditions was used for the terrestrial secondary consumer pathway. Note that there are no endorsed ecological screening criteria for PFHxS in Australia and so an assessment was not done.

Human health risks were assessed for the sum of PFOS and PFHxS (PFOS+PFHxS) according to current national guidance, and PFOA. Screening criteria from the PFAS NEMP 2.0 were used where available and a human health risk quotient (RQ_{HH}) was calculated by dividing the estimated biosolids-amended soil concentrations by relevant screening criteria. If no screening criteria were available, exposures were estimated by calculating predicted daily intakes (µg/kg/day) and RQ_{HH} were derived using a toxicity reference value.

A risk quotient larger than 1 indicates there is a risk to the environment or human health. Risk quotients were derived for a range of exposure pathways under four Scenarios, and the key exposure pathway is the one that produced the highest risk quotient for each scenario. The threshold derivation process is based on the key exposure pathways to make sure all relevant human health and ecological pathways are protected. In this HHERA if the risk quotient for the key exposure pathway was greater than 0.2, regulation is recommended.

A risk quotient larger than 0.2 instead of 1 allows for a margin of safety of 5, to account for uncertainty in

- biosolids PFAS concentrations - this risk assessment is based on PFAS concentrations from 20 STPs across NSW, and if, or the extent to which, these concentrations vary over time is unknown.
- potential risk from other PFAS or precursor compounds as these cannot be quantitatively accounted for in risk assessments - this risk assessment focused only on PFOS, PFOA and PFOS+PFHxS so some additional conservatism is needed.

Where risk quotients were equal to or less than 0.2 the risk from that pathway was considered to be low. If this was the case for all pathways for a scenario, it was concluded that a threshold was not necessary based on the available data. This may need to be reviewed if additional data shows a large variation in concentrations above the 5-fold margin of safety.

5.3.2. Results from each scenario

Scenario 1 – 'unrestricted use' biosolids in residential gardens

Scenario 1 assessed the ecological and human health risks from the use of 'unrestricted use' biosolids in a residential garden. This scenario assumed biosolids are processed with another waste material (e.g. garden waste) containing no PFAS, in a ratio of 1-part biosolids to 2-parts other waste. For the risk assessment it was assumed that 'unrestricted use' biosolids could be applied to a residential garden without any restrictions on application rates, effectively as an entire growing medium. Therefore, concentrations of PFOS, PFOA and PFHxS in the 'unrestricted use' biosolids were estimated, and these were used as the biosolids-amended soil concentrations in the risk calculations.

The ecological assessment considered direct toxicity to terrestrial organisms as the only relevant ecological exposure pathway in this scenario. For both PFOS and PFOA, all risk quotients were less than 0.2, indicating that the risk is low.

Human health risks from PFOS+PFHxS and PFOA were assessed for three exposure pathways: incidental ingestion of soil/dust, consumption of home-grown fruit/vegetables and the consumption of home chicken eggs. For PFOA, all RQ_{HH} values were less than 0.2 indicating the risk is low. For PFOS+PFHxS, the RQ_{HH} values ranged up to 2.9, indicating the need to derive a regulatory threshold. The key exposure pathway for this scenario was incidental ingestion of soil/dust and consumption of home-grown fruit/vegetables (RQ_{HH} values up to 2.9).

Scenario 2 – 'unrestricted use' biosolids for land rehabilitation

Scenario 2 assessed the ecological and human health risks from land application of 'unrestricted use' biosolids for land rehabilitation. The same assumptions for unrestricted use biosolids apply as for Scenario 1.

Ecological risks from PFOS and PFOA were assessed for three exposure pathways: direct toxicity to terrestrial organisms, toxicity to secondary consumers and toxicity to off-site aquatic organisms. For direct toxicity to terrestrial organisms and toxicity to off-site aquatic organisms, all RQ_{ECO} values were less than 0.2, indicating that the risk is low. For the toxicity to secondary consumers pathway, the maximum RQ_{ECO} value for PFOS was 2.6 and for PFOA it was 0.8.

The assessment of human health risks considered two pathways: incidental ingestion of soil/dust and consumption of drinking water. All RQ_{HH} values were less than 0.2 indicating that risks to human health are low. The highest PFOS+PFHxS RQ_{HH} for the drinking water pathway was 0.2. Considering how difficult it is to estimate PFAS concentrations in drinking water, the HHERA recommended that PFAS be measured in groundwater and surface water in close proximity to land rehabilitated with biosolids to confirm that concentrations do not pose risk to human health.

The key exposure pathway for Scenario 2 was for ecological secondary consumers (RQ_{ECO} values up to 2.6 and 0.8 for PFOS and PFOA, respectively) The threshold derived for unrestricted use biosolids should be protective of this pathway.

Scenario 3 – 'restricted use' biosolids in agriculture

Scenario 3 assessed the ecological and human health risks from PFOS, PFOA and PFHxS following land application of 'restricted use' biosolids in agriculture. Three ecological exposure pathways (direct toxicity to terrestrial organisms, toxicity to secondary consumers and toxicity to off-site aquatic organisms) and 11 human health exposure pathways (including incidental ingestion of soil/dust, home consumption of crops (fruit and vegetables), beef and milk) were assessed. The potential risk to public health from market supply of agricultural products from biosolids-amended land was not assessed. Risks specifically refer to the consumption of home grown produce.

This scenario assumed that biosolids are land applied and incorporated into the soil (i.e. biosolids-amended soil). Risks were assessed based on estimated concentrations in the biosolids-amended soil and soil pore water for each of the following land application rates:

- 10 tonnes per hectare (t/ha) single and repeat applications
- 50 t/ha single and repeat applications

Repeat applications assumed biosolids were applied every five years for 30 years. Fifty t/ha repeat application was considered to be a realistic maximum biosolids application rate for agriculture.

Ecological risks from direct toxicity to terrestrial organisms and off-site aquatic organisms were low for PFOS and PFOA for all application rates assessed. For indirect exposure to secondary consumers, the maximum RQ_{ECO} values were 2.0 for PFOS and 0.62 for PFOA.

The human health pathways posed a higher potential risk than ecological pathways, making them the key risk-driving pathways for this scenario. For PFOS+PFHxS, the beef and milk grazing and fodder pathways resulted in RQ_{HH} values ranging up to 18. For PFOA, there were no human health pathways that resulted in RQ_{HH} values above 1. However, for the milk grazing and fodder pathways, the maximum RQ_{HH} was 0.45.

The HHERA recommended that thresholds are derived for both PFOS+PFHxS and PFOA for the key exposure pathway of milk consumption from dairy cows grazing on biosolids-amended soil (RQ_{HH} value of 18 for PFOS+PFHxS) and indirect exposure to secondary consumers (RQ_{ECO} value of 0.62 for PFOA).

Monitoring of PFAS in groundwater and surface waters in the proximity of biosolids land application in agriculture is recommended as predicting PFAS concentrations in water bodies from soils/biosolids is difficult. Measuring PFAS in the environment will provide more certainty in understanding the potential risks to drinking water and aquatic environments and inform management needs for biosolids application.

Scenario 4 – 'unrestricted use' biosolids in agriculture

To determine if the risks from unrestricted use biosolids via agricultural pathways are higher than those identified in Scenarios 1 and 2, an additional scenario was assessed. Only the highest risk agricultural pathway from Scenario 3 for restricted use was assessed for unrestricted use and presented here.

The maximum RQ_{HH} values for PFOS+PFHxS for Scenario 4 was 23. This is higher than the RQ_{HH} values calculated for unrestricted use biosolids in Scenarios 1 and 2. Therefore, this pathway should be used for threshold derivation. In contrast, the maximum RQ_{HH} values for PFOA for Scenario 4 (0.58) were not the highest and are not the key risk driving pathway for PFOA in unrestricted use biosolids.

5.3.3. Recommendations and next steps

The HHERA indicated that PFAS in unrestricted use and restricted use biosolids should be regulated and thresholds should be derived to make sure applying biosolids to land poses a low risk to the environment and human health. The HHERA also recommended the following:

- Derivation of thresholds should be based on the key exposure pathway driving risk which will then be protective of all other assessed exposure pathways.
- Thresholds for unrestricted use biosolids should apply to the final material destined for land application to make sure additional contamination is not introduced if the biosolids are processed with other waste.
- Threshold derivation should be based on realistic maximum exposures to be protective but not over-conservative. The assumptions used should be transparent and applicable to other emerging contaminants considered in the NSW Biosolids Regulatory Review.

- If PFAS toxicity reference values in Australia are changed in the future, or additional toxicity reference values for other PFAS compounds endorsed, the HHERA should be revised to make sure the key exposure pathways are still correct.
- Monitoring groundwater and surface waters in close proximity to areas where biosolids have been applied for land rehabilitation or in agriculture should be done to address uncertainties in estimating PFAS concentrations in water bodies based on soils/biosolids concentrations. This is important to provide certainty that potential human health and ecological risks in water supplies and aquatic systems are low.

5.4. PBDEs, triclosan, Galaxolide, and chlordane HHERA

The aim of this HHERA[4] was to determine if PBDEs, triclosan, and Galaxolide in biosolids need to be regulated and whether current regulation of chlordane should continue. The key exposure pathways for deriving regulatory thresholds were identified.

PBDEs are used as flame retardants in many products including building materials, motor vehicles and textiles. PBDEs have 209 congeners but can be subdivided based on the level of bromination which varies between 1-10 bromine atoms per molecule. Several international studies have indicated that the most toxic and bioaccumulative congeners are in the 4 to 6 bromine atoms range – known as BDE-47, BDE-99 and BDE-153, respectively. The United States Environmental Protection Agency (USEPA) also lists the fully brominated PBDE (BDE-209) as a contaminant of emerging concern because of its potential to transform into other PBDE congeners. Further PBDEs are recognised as endocrine disruptors that interfere with human reproduction and neurodevelopment.

Galaxolide (HHCB) is a commonly used fragrance ingredient in many cleaning and personal care products as well as marine and automotive aftermarket products such as coatings.

Triclosan is an antimicrobial agent used in cosmetics and personal care products that ends up in wastewater. The US Food and Drug Administration banned the sale of over-the-counter consumer soaps and antiseptic products containing triclosan in 2017 because there wasn't enough scientific evidence that anti-bacterial hand soaps were more effective than washing with soap and water. Triclosan is recognised as an endocrine disruptor because of its ability to interfere with human hormone systems, including the thyroid.

The production and use of the pesticide **chlordane** were phased out in Australia by the end of 1997. However, because it was so widely used, it is still being detected in biosolids today.

5.4.1. Data

For PBDEs, triclosan and Galaxolide the data was sourced from the 2017 EPA biosolids sampling campaign. There were laboratory quality control issues with recoveries of chlordane from this campaign and so the data was not used for risk assessment. An alternative chlordane dataset which contained monitoring data from 33 STPs across NSW collected between 1996 and 2016 was available. The risk assessment was done using the chlordane data from 2016 only, which included data from 24 STPs.

[4] NSW Department of Planning and Environment, Environment and Heritage Group 2023. *NSW Biosolids Guideline Review: Identification of key exposure pathways to assess risks from HHCB, triclosan, chlordane and PBDEs in biosolids*. (Available on the EPA website.)

The type of risk assessment needed for each contaminant was determined by the outcomes of the Contaminants Review. Galaxolide, triclosan and chlordane were identified as contaminants with potential ecological risks so an ecological risk assessment was completed. This aligns with information released by the Australian Industrial Chemicals Introduction Scheme in 2021 that categorised Galaxolide as having acute and chronic toxicity to aquatic life with long lasting effects. PBDEs and chlordane were identified as contaminants with possible dietary exposure and potential risks to human health so a human health risk assessment was completed.

An ecological risk assessment (Galaxolide, triclosan and chlordane) and human health risk assessment (PBDEs and chlordane) were completed considering the same four scenarios of biosolids use as described above for the PFAS HHERA. The 95% upper confidence limit of the mean (95UCL) and the maximum concentrations[5] for each contaminant were used.

- **Galaxolide** was detected in all biosolids samples collected by the EPA and concentrations ranged from 420 to 68,000 µg/kg dry weight (dw) (95UCL = 30,000 µg/kg dw).
- **Triclosan** was detected in biosolids from all but one of the STPs sampled and concentrations ranged from < 30 µg/kg (< limit of reporting) to 18,000 µg/kg dw (95UCL = 5500 µg/kg dw).
- For the **PBDE** risk assessment, data were separated into two groups, Br1-Br9 (sum of PBDEs with between 1 and 9 bromine atoms) and Br10 (fully brominated deca-BDE). This was done due to differences in toxicity and environmental fate between these groups.
- PBDE compounds in the **Br1-Br9** group were detected in all biosolids samples collected by the EPA and concentrations ranged from 17 to 240 µg/kg dw (95UCL = 110 µg/kg dw).
- **Deca-BDE (Br10)** was detected in all biosolids samples, and concentrations ranged from 50 to 210,000 µg/kg dw (95UCL = 23,000 µg/kg dw). The maximum Br10 concentration occurred in one STP and was 300-fold higher compared to the next highest concentration (700 µg/kg dw). To address this, the risk assessment was conducted for Br10 using both the full dataset (i.e. maximum = 210,000 µg/kg and 95UCL = 23,000 µg/kg) and the dataset omitting the exceptionally high data from the one STP (i.e. maximum = 700 µg/kg and 95UCL = 360 µg/kg).
- **Chlordane** was detected in approximately 40% of the samples and concentrations ranged from < 5 to 140 µg/kg (sum of *cis*- and *trans*-chlordane) (95UCL = 12 µg/kg dw). Due to the extensive chlordane dataset, the 95th percentile of chlordane concentrations was used as the 'maximum' concentration in the chlordane risk assessments (i.e. 30 µg/kg dw). This was done to represent a realistic maximum concentration but also remove any concentrations that were abnormally high. This approach was not used for the other contaminants due to the small dataset that did not account for temporal variability.

The risk assessment methodology for both ecological and human health was based on the PFAS biosolids HHERA described above. The risk assessment was carried out according to current national guidance.

5.4.2. Results from each scenario

Scenario 1 – 'unrestricted use' biosolids in residential gardens

Scenario 1 assessed the ecological and human health risk from use of 'unrestricted use' biosolids in a residential garden using the same assumptions described in scenario 1 for PFAS. The ecological assessment considered direct toxicity to terrestrial organisms as the only relevant

[5] For chlordane, the 95th percentile was used as the 'maximum' concentration due to the large dataset available (approx. 300 measurements)

ecological exposure pathway in this scenario. The RQ_{ECO} values were more than 1 for Galaxolide and triclosan (30 and 92, respectively), and ranged up to 0.25 for chlordane.

Human health risks were assessed for PBDEs and chlordane for five exposure pathways: incidental ingestion of soil/dust, incidental inhalation of dust, dermal absorption, consumption of homegrown fruit/vegetables and consumption of homegrown chicken eggs. For Br1-Br9 and Br10, the highest RQ_{HH} values ranged up to 2 and 7.6, respectively for eating eggs. For chlordane, all RQ_{HH} values were less than 0.2.

Based on these results, the HHERA recommended that thresholds for Galaxolide, triclosan, PBDEs and chlordane in unrestricted use biosolids are derived for key exposure pathways. The key exposure pathway for Galaxolide, triclosan and chlordane was ecological toxicity to terrestrial organisms. For PBDEs (Br1-Br9 and Br 10), the key exposure pathway was for human health for the consumption of homegrown chicken eggs.

Scenario 2 – 'unrestricted use' biosolids for land rehabilitation

Scenario 2 assessed the ecological and human health risk from land application of 'unrestricted use' biosolids for land rehabilitation. This scenario assumed the land is used for public open space in the future and is not used for agriculture. The same assumptions for unrestricted use biosolids apply as for scenario 1.

Ecological risks were assessed for three exposure pathways: direct toxicity to terrestrial organisms, toxicity to secondary consumers and toxicity to off-site aquatic organisms. For Galaxolide, triclosan and chlordane, RQ_{ECO} values were more than 1 (RQ_{ECO} values up to 30, 92 and 2.6, respectively) in at least one of the assessed exposure pathways.

Human health risks were assessed for PBDEs and chlordane for four exposure pathways: incidental ingestion of soil and dust, incidental inhalation of dust, dermal absorption and consumption of drinking water. All RQ_{HH} values for PBDEs and chlordane were less than 0.2 for all pathways, indicating that risks to human health following land application of unrestricted use biosolids in land rehabilitation are low.

Based on these results, the HHERA recommended that thresholds are derived for Galaxolide, triclosan and chlordane. For Galaxolide and triclosan, the key exposure pathway with the highest risk quotient value was direct toxicity to terrestrial organisms. For chlordane, the key exposure pathway with the highest risk quotient value was toxicity to secondary consumers. Thresholds derived for unrestricted use biosolids should be protective of these pathways.

Scenario 3 – 'restricted use' biosolids in agriculture

Scenario 3 assessed ecological and human health risk from land application of 'restricted use' biosolids in agriculture. Three ecological exposure pathways were assessed; direct toxicity to terrestrial organisms, toxicity to secondary consumers and toxicity to offsite aquatic organisms. Several human health exposure pathways were also assessed: incidental exposure (ingestion, inhalation and dermal), home consumptions of crops (fruit and vegetables), beef and milk, and drinking water. The potential risk to public health from market supply of agricultural products from biosolids-amended land was not assessed. Risks specifically refer to the consumption of home grown produce.

This scenario assumed that biosolids are land applied and incorporated into the soil (i.e. biosolids-amended soil) with the same assumptions and application rates detailed for scenario 3 in the PFAS HHERA.

For ecological risks, RQ_{ECO} values for Galaxolide were more than 1 for direct toxicity to terrestrial organisms and toxicity to secondary consumers (RQ_{ECO} up to 24). For triclosan all three assessed exposure pathways resulted in RQ_{ECO} values above 1 (RQ_{ECO} up to 72) and for chlordane exposure to secondary consumers resulted in RQ_{ECO} above 1 (maximum RQ_{ECO} = 2.0).

Human health risks were assessed for PBDEs (Br1-Br9 and Br10) and chlordane. For Br1-Br9, the consumption of beef and milk from grazing and fodder-fed cattle/dairy cows resulted in RQ_{HH} values above 1, ranging up to 12. For Br10 the maximum RQ_{HH} value was 1.1 for the consumption of beef from grazing cattle, although this value was driven by the high concentration of Br10 in one STP. Excluding this high value, all RQ_{HH} values for Br10 were below 0.2. For chlordane, all RQ_{HH} values were less than 0.2 (maximum RQ_{HH} = 0.11).

Based on these results it was recommended that thresholds for Galaxolide, triclosan, PBDEs and chlordane are derived for 'restricted use' biosolids. The key exposure pathways for Galaxolide and triclosan were ecological direct toxicity to terrestrial organisms. For chlordane, the ecological pathways were also the most sensitive with the key pathway identified as toxicity to terrestrial secondary consumers. For PBDEs the key exposure pathway was beef consumption from grazing cattle for both Br1-Br9 and Br10.

Scenario 4 (additional scenario) – 'unrestricted use' biosolids in agriculture

To determine if the risks from unrestricted use biosolids via agricultural pathways are potentially higher than those identified in Scenarios 1 and 2 this additional scenario was assessed. This scenario only focused on human health pathways and only the highest risk agricultural pathways (determined from Scenario 3) are presented. The ecological pathways were not included as all relevant pathways for unrestricted use were already assessed in Scenarios 1 and 2.

The maximum RQ_{HH} value for Br1-Br9 was 16 (beef from grazing cattle). This was higher than the values calculated for unrestricted use biosolids in Scenarios 1 and 2. In contrast, the values from Scenario 4 for Br10 and chlordane (maximum = 1.5 and 0.14, respectively) were not the highest. Therefore, this is not considered the key risk driving pathway for these two compounds in unrestricted use biosolids.

5.4.3. Recommendations

The results of the HHERA indicated that Galaxolide, triclosan, PBDEs (Br1-Br9 and Br10) and chlordane need regulation in unrestricted use and restricted use biosolids to make sure land application of biosolids poses a low risk to the environment and human health.

In addition, the derivation of thresholds should be based on realistic maximum exposures to be protective but not overly conservative. The derivation process using these assumptions should be transparent and applicable to other contaminants considered in the Biosolids Guidelines review.

5.5. Derivation of regulatory thresholds for PFAS, PBDEs, Galaxolide, triclosan and chlordane

Other than chlordane these contaminants are not currently regulated in NSW biosolids. Risks from these contaminants were assessed to identify key exposure pathways (Table 5). The results indicated that they need regulation and that thresholds should be derived to make sure they pose a low risk to the environment and human health when biosolids are applied to land.

A 'backwards' risk assessment approach was used to derive thresholds based on the key exposure pathways identified in the risk assessments[6]. In most cases, the thresholds apply to

---

[6] NSW Department of Planning and Environment, Environment and Heritage Group 2023. *NSW Biosolids Guideline Review: Threshold derivation for contaminants in biosolids – PFAS, HHCB, triclosan, PBDEs and chlordane*. (As on the EPA website.)

individual compounds. However, for PBDEs, which are a large group of individual compounds, the thresholds are presented as two groups: Br1-Br9 (sum of PBDEs with between 1 and 9 bromine atoms) and Br10 (fully brominated deca-BDE). This was done due to differences in toxicity and environmental fate between these two groups. For PFAS, which are also a large group of compounds, thresholds have only been derived for the sum of PFOS and PFHxS, and for PFOA.

Thresholds were derived with a 5- and 2-fold margin of safety, as well as with no margin of safety (

Table 6). The EPA's selection of the most appropriate margin of safety for regulation will depend on a range of factors including the presence of other contaminants in the biosolids and the potential for exposure via multiple pathways.

As well as the biosolids thresholds, MASCCs were also derived based on agricultural use of biosolids (Table 6). These values can be used to calculate a contaminant limiting biosolids application rate (CLBAR), which is consistent with the approach used in the current Biosolids Guidelines.

Table 5: Key exposure pathways used for deriving thresholds for unrestricted and restricted use biosolids

Contaminant	Unrestricted use biosolids	Restricted use biosolids
PFOS+PFHxS	Human consumption of milk from grazing dairy cows	Human consumption of milk from grazing dairy cows
PFOA	Ecological toxicity to secondary consumers	Ecological toxicity to secondary consumers
HHCB	Ecological direct toxicity to terrestrial organisms	Ecological direct toxicity to terrestrial organisms
Triclosan	Ecological direct toxicity to terrestrial organisms	Ecological direct toxicity to terrestrial organisms
Br1-Br9	Human consumption of beef from grazing cattle	Human consumption of beef from grazing cattle
Br10	Human consumption of chicken eggs	Human consumption of beef from grazing cattle
Chlordane	Ecological toxicity to secondary consumers	Ecological toxicity to secondary consumers

Table 6: Risk-based contaminant thresholds for unrestricted use biosolids, restricted use biosolids and MASCC at three margins of safety (all concentrations shown in µg/kg)

Contaminant(s)	Margin of safety	Unrestricted use threshold*	Restricted use threshold	MASCC
PFOS+PFHxS	5	0.22	6.2	0.22
	2	0.55	15	0.55
	1	1.1	31	1.1
PFOA#	5	2	54	2
	2	5	130	5
	1	10	270	10
HHCB	5	150	4,000	150
	2	375	10,000	375
	1	750	20,000	750
Triclosan	5	13	350	13
	2	32	870	32
	1	65	1,700	65
Br1-Br9	5	1.0	28	1.0
	2	2.6	70	2.6
	1	5.1	140	5.1
Br10	5	5,600	260,000	9600
	2	14,000	650,000	24,000
	1	28,000	1,300,000	48,000
Chlordane	5	0.78	21	0.78
	2	1.9	52	1.9
	1	3.9	100	3.9

* unrestricted use thresholds should be applied to the final biosolids product.

PFOA thresholds and MASCCs were derived to protect ecological secondary consumers and are based on a soil screening criterion adjusted from the United Kingdom. Work for the PFAS NEMP derived a PFOA soil screening criteria for indirect exposure (secondary consumers).

The EPA is proposing to apply these thresholds to all biosolids beneficially applied to land in NSW. Further changes to the criteria for PFOS+PFHxS and PFOA will be considered following the publication of the NEMP 3.

5.6. Heavy Metals

There are nine heavy metals currently regulated in NSW biosolids (Table 7). Research in the 25 years since these regulatory criteria were set indicates that some changes are needed to make sure risks to the environment and human health are minimal. The Contaminants Review identified another nine heavy metals not currently regulated in NSW biosolids, and recommended monitoring and assessment to determine the need for future regulation (Table 7). Discussion is provided below for

(i) heavy metals for which existing regulatory requirements will be continued
(ii) currently regulated heavy metals for which changes are proposed, and

(iii) heavy metals not currently regulated but identified as needing monitoring and assessment in NSW to inform possible future regulation.

Note that for some heavy metals in group (i) additional data may indicate that ongoing testing and regulatory limits are no longer needed.

Key sources informing the review of regulatory settings for heavy metals in biosolids were

- the research and recommendations of the National Biosolids Research Program
- the contaminants review
- the National Geochemical Survey of Australia soil heavy metal concentrations
- the National Environment Protection Measure – assessment of site contamination
- total diet studies by Food Standards Australian New Zealand
- regulatory limits in other jurisdictions
- peer reviewed scientific literature.

Table 7: Regulatory status of heavy metals in NSW biosolids

Currently regulated	Under consideration
Arsenic (As)	Antimony (Sb)
Cadmium (Cd)	Barium (Ba)
Chromium (total) (Cr)	Beryllium (Be)
Copper (Cu)	Chromium (VI) (Cr)
Lead (Pb)	Manganese (Mn)
Mercury (Hg)	Molybdenum (Mo)
Nickel (Ni)	Silver (Ag)
Selenium (Se)	Titanium (Ti)
Zinc (Zn)	Vanadium (V)

Regardless of whether changes are proposed based on minimising risks to the environment and human health from heavy metal contamination, change would be needed if the EPA decides to introduce a new contaminant grading system outlined in section 4.2 above. The revised contaminant grading system that is being considered by the EPA would reduce the number of contaminant grades from five (A-E) to two (C1 or C2). In general, C1 and C2 are the same as current grade A and C concentration limits, with exceptions outlined in the following sections.

The MASCC for each heavy metal at sites receiving land applied biosolids is currently prescribed for two land uses: agricultural and non-agricultural sites. A single MASCC is proposed here regardless of land use. Protection of the soil resource to ensure its ability to perform ecosystem functions for future generations means that the distinction between agricultural land use and land uses not associated with food production is not relevant. Except for Cd and Cu the revised MASCCs align with C1 biosolids concentrations. Further details are provided for these heavy metals in the following sections.

Table 8 summarises the EPA's proposed absolute maximum concentrations of each heavy metal in biosolids as well as the MASCC for all biosolids beneficially applied to land in NSW.

Table 8: Proposed concentration limits for contaminant grades C1 and C2 and the MASCC (mg/kg dw)

Heavy metal	C1	C2	MASCC
Arsenic	20	20	20
Cadmium	1	5	0.5
Copper	150	1,000	100
Chromium (total)	100	500	100
Lead	150	420	150
Mercury	1	4	1
Nickel	60	270	60
Selenium	5	50	5
Zinc	200	1,000	200

5.6.1. Existing requirements to be continued

No changes are proposed for arsenic, chromium, lead, nickel and selenium. Grade A and C criteria have been adopted for C1 and C2 limits. Future monitoring data may support the removal of these heavy metals (and mercury) from routine monitoring if a MASCC was kept. There is some evidence of the need to regulate Cr(VI), however NSW data on Cr(VI) in biosolids are needed before this can be assessed to inform any future changes.

For mercury the C2 limit is the previous Grade B limit of 4 mg/kg rather than grade C of 15 mg/kg. Soil concentrations of mercury in NSW typically range from <0.01 – 0.23 mg/kg with a median of 0.02 mg/kg and 90th percentile of 0.06 mg/kg. Concentrations of mercury in NSW biosolids range from 0-25 mg/kg with a median of 1.3 mg/kg and a 90th percentile of 3.1 mg/kg. The average mercury concentration in biosolids assessed in the NBRP was 3 mg/kg.

Mercury is toxic to humans with no known function in the body at any concentration. Environmental risk centres on bioaccumulation and secondary poisoning to organisms. The preliminary risk characterisation undertaken for the Contaminants Review identified a potential risk from mercury at the lowest application rate assessed (a single application at 8 t/ha). The National Biosolids Research Program prioritised cadmium over mercury for detailed assessment as the most recent Food Standards Australian New Zealand Total Diet Study at the time (2003) determined that cadmium was twice as hazardous to human health as mercury.

There is evidence to indicate current limits for mercury are not protective enough. In the absence of more specific, detailed risk assessment a precautious approach is needed. This is consistent with the limits set in other resource recovery orders and exemptions and with the limit on mercury contamination in fertiliser.

Further consideration of threshold limits for arsenic, chromium, lead, nickel, selenium and mercury will be informed by the results of the EPA's biosolids sampling project and site monitoring data. A MASCC should stay in place to make sure high levels of heavy metals are not applied to soils through biosolids.

5.6.2. Changes proposed

C1 and C2 concentration limits have not been taken from existing A and C contaminant grades. There is evidence that current regulatory limits for these heavy metals don't protect human health or the environment and so the recommendations of the National Biosolids Research Program have been considered by the EPA in determining the proposed regulatory settings outlined below.

The National Biosolids Research Program was a coalition of seven research agencies from across Australia that was set up by the CSIRO in 2002. Before this, a preliminary hazard assessment was conducted to determine the metals that would be the focus of the program. This identified copper, cadmium and zinc to be the main focus of the work based on the likely dietary exposure of people from food crops (cadmium) and on risks to plants and soil health (copper, zinc). The National Biosolids Research Program investigated the land application of biosolids at 20 agricultural sites with a range of soil types and climatic conditions around Australia. This research looked at the bioavailability of the metals in biosolids and examined three endpoints: food quality, crop production and soil health (indicated by impacts on microbial nitrification and respiration). The work determined that critical soil concentrations were affected by soil properties and recommended specific maximum concentrations for cadmium, copper and zinc that are dependent on soil pH and on either soil clay content, organic carbon content or cation exchange capacity.

5.6.3. Cadmium

Cadmium is highly toxic to humans and is also toxic to several aquatic organisms, plants, and microbial species. Cadmium toxicity presents a high risk to human and environmental health because it is bioaccumulative (accumulating in tissues over time), as opposed to many other metal contaminants which act by direct toxicity to an organism. There are risks to human health via uptake of cadmium into plants (food crops). Plant uptake occurs at concentrations that are harmful to human health before any adverse impact is seen for plant health.

Cadmium is present in NSW soil in the range 0.1 - 0.79 mg/kg, with a mean of 0.2 and 90th percentile of 0.43 mg/kg. Available cadmium data for NSW biosolids ranges from 0.05 to 34 mg/kg, with a median of 1.9 mg/kg and a 90th percentile of 3.97 mg/kg.

The National Biosolids Research Program carried out a hazard assessment to determine which heavy metals it would focus on. Cadmium was identified as a main focus based on the likely dietary exposure of people from food crops. Critical soil concentrations of cadmium that would lead to the Food Standards Australian New Zealand standard (0.1 mg/kg) for human consumption being exceeded were determined across all National Biosolids Research Program sites using wheat as a representative species. The critical values could be predicted through knowledge of soil properties, mainly soil pH and clay content and accounted for cadmium bioavailability. These critical soil values ranged from 0.54 to 2.20 mg/kg, depending on soil properties.

Revision of cadmium regulation in biosolids is needed as the current limits are not protective enough to make sure crops (such as wheat) do not go over Food Standards Australian New Zealand limits[7] in foods. The current Biosolids Guidelines noted the intention to review the Grade A limit for cadmium, with the expectation that this would be reduced to be equivalent with the MASCC of 1 mg/kg dw biosolids. When setting the revised MASCC it was determined that 1 mg/kg would not be protective enough of all soil types because in low clay, low pH soils, soil cadmium levels of 1 mg/kg may pose a risk to the food chain.

The EPA is proposing to set the cadmium C1 limit to 1 mg/kg, a C2 limit to 5 mg/kg (current Grade B limit), and set the MASCC to 0.5 mg/kg. A maximum permissible contaminant load of 0.15 kg Cd/ha per 5-year period is also proposed.

5.6.4. Copper

Copper is an essential micronutrient needed by plants for a range of enzymatic activities, and chlorophyll and seed production. Too much copper is toxic to soil microbes affecting respiration

---

[7] Australia New Zealand Food Standards Code: Schedule 19 – Maximum levels of contaminants and natural toxicants, available at https://www.legislation.gov.au/Details/F2021C00628 at the time of writing.

and nitrification. Too much copper is also toxic to plants, for example causing reduced grain yield and growth in wheat. Evidence indicates the relatively high concentrations of copper in biosolids will impact soil microbial health and current regulatory limits need to be revised. No evidence of copper toxicity to humans was identified through exposure routes relevant to the production and beneficial reuse of biosolids.

Copper concentrations in NSW soil range from 3.5 – 118 mg/kg with a median of 19.85 and a 90th percentile of 30.6 mg/kg. Available data for NSW biosolids range from 1.4 – 1620 mg/kg, with a median of 537 and 90th percentile of 916 mg/kg.

Microbial respiration is sensitive to the soil copper concentration but is not affected by soil properties. However for a given Cu concentration, impacts on microbial nitrification were affected by soil pH and cation exchange capacity.

Having considered impacts to both plants and microbes and the associated correlations with soil properties and copper bioavailability, the National Biosolids Research Program proposed a matrix of thresholds so that adverse impacts to plants and/or microbes from Cu in biosolids were less likely. The maximum allowed *added* copper concentration to minimise adverse effects in different soil types ranged from 25 to 245 mg/kg. This is an “added risk” approach which separates naturally occurring concentrations of a given contaminant from the concentrations added to derive a trigger value. The underlying assumption is that the availability of the background contaminant concentration is not a risk to the ecosystem. The background concentrations are considered to have shaped the ecosystems, and to meet the micronutrient needs of organisms in the local environment.

A follow up study of National Biosolids Research Program sites 12 years later by Shaw et al (2020) looked at microbial diversity and agricultural soil function regarding copper exposure. Sites with added concentrations of copper up to 200 mg/kg retained similar functionality to control plots, while higher concentrations of added copper were associated with reduced functionality. Although plots receiving high concentrations of added copper retained high diversity (as determined by genetic analyses), the lack of associated functionality at these sites prompted the hypothesis that the high concentrations of copper induced dormancy in some of the microbial species present.

When considering whether to adopt the recommendations of the National Biosolids Research Program, the EPA considered the complexities of setting limits that depend on soil properties. For example, the need for biosolids users to characterise the attributes of their soil, and the need for that characterisation to account for intra-site variability (i.e. a robust sampling plan would be needed to work out representative soil conditions upon which selection of an appropriate threshold could be based). Also, the approach of restricting the amount of copper that can be added (rather than the total) introduces complexities when determining an equivalent to the MASCC.

Instead, the EPA determined that the risks identified in the National Biosolids Research Program can be managed in a simple way. The thresholds for C1 and C2 are set at a level that, when biosolids are applied at reasonable application rates (ranging up to 50 t/ha and beyond), prevent the application of copper at levels associated with identified risk, based on the National Biosolids Research Program findings and irrespective of the properties of the receiving soil.

The EPA is proposing to set the copper C1 limit to 150 mg/kg, the C2 limit to 1000 mg/kg, and the MASCC to 100 mg/kg.

5.6.5. Zinc

Zinc is an essential mineral necessary for the activity of hundreds of enzymes in the human body. It has relatively low toxicity to humans unless too much is inhaled or consumed. While zinc is essential for plant growth, too much of it in soil is toxic to soil microbial processes including respiration and nitrification. Phytotoxicity of zinc has also been observed and was characterised for common Australian crops as part of the work of the National Biosolids Research Program.

Zinc is present in NSW soil in concentrations ranging from 7 – 210 mg/kg with a mean of 65.2 and a 90th percentile of 87.7 mg/kg. Available data for NSW biosolids ranges from 0.25 – 4370 mg/kg with a median of 780 and a 90th percentile of 1160 mg/kg.

The National Biosolids Research Program looked at the toxicity of zinc is to agricultural crop species (crop growth and yield) and soil health (microbial respiration and nitrification). For wheat, as the most sensitive crop studied, zinc toxicity was most closely associated with soil pH and cation exchange capacity. Microbial impacts were also identified, with respiration more sensitive to zinc than nitrification. Impacts to microbial respiration were not associated with particular soil properties, while impacts on microbial nitrification were associated with soil pH. The National Biosolids Research Program determined important concentrations of added zinc that adversely affected microbial processes and plant productivity and accordingly derived soil specific maximum limits. These ranged from 20 to 300 mg/kg and were strongly dependent on soil properties.

Similar to that described above for copper, when considering whether to adopt the recommendations of the National Biosolids Research Program the EPA considered the complexities of setting limits that depend on soil properties. Instead, the EPA determined that the risks identified in the National Biosolids Research Program can be managed in a simple way. The thresholds for C1 and C2 are set at a level that, when biosolids are applied at reasonable application rates (ranging up to 50 t/ha and beyond), prevent the application of zinc at levels associated with identified risk, based on the National Biosolids Research Program findings and irrespective of the properties of the receiving soil.

The EPA is proposing to set the zinc C1 limit to 200 mg/kg, the C2 limit to 1000 mg/kg, and the MASCC to 200 mg/kg.

5.6.6. Monitoring and assessment proposed

The additional nine heavy metals proposed for future monitoring, assessment and potential regulation were identified through the Contaminants Review.

Reasons for adding them vary for each heavy metal and includes toxicological potency, routine measurement in other jurisdictions and potential risks identified in hazard screening assessments. However, there is a lack of NSW data for them to support risk assessment and regulatory inclusion. Additional data will be sought during the EPA biosolids sampling project and via requests for data from the STPs.

5.7. Persistent organic pollutants

The Biosolids Guidelines contain regulatory thresholds for a range of heavy metals as well as some persistent organic pollutants (POPs). The POPs include organochlorine pesticides (OCPs) and polychlorinated biphenyls (PCBs) which have been banned in Australia since the mid-1980s although several of these compounds can be produced unintentionally. The guideline review will determine whether there is a basis for continued regulation of these compounds or whether they can be removed from testing requirements:

- DDT/DDD/DDE
- Aldrin
- Dieldrin
- Chlordane
- Heptachlor
- HCB (hexachlorobenzene)
- Lindane
- BHC (benzene hexachloride)
- PCBs

The (now) Department of Planning and Environment did a preliminary analysis of monitoring data spanning over 20 years to examine trends in concentrations. Ecological risk assessment was also conducted to determine potential risks to the environment. Data was mostly collected from STPs in coastal NSW from the Shoalhaven, Sydney and Hunter regions.

Elevated concentrations of a range of persistent organochlorine compounds in were observed in the data set. OCPs and PCBs are still found in biosolids despite being banned in Australia in 2004. The main OCPs detected in the dataset were chlordane, dieldrin and PCB.

Average, median and maximum concentrations of OCPs, especially aldrin, chlordane and dieldrin, indicate potential ecological risk even when considering incorporation into soils. The analysis did not assess human health risk.

The EPA is proposing to continue to regulate OCPs, and will review the current thresholds when it has additional data to make sure they are protective of the most sensitive receptors. Note that this has been done for chlordane as detailed in the HHERA results above.

5.8. Contaminants of known or emerging concern

The EPA regulates a limited range of commonly occurring inorganic contaminants and POPs in biosolids based on environmental risk. Recent advances in analytical techniques have led to increasing detection of “contaminants of known or emerging concern”.

The USEPA defines contaminants of known or emerging concern as “a chemical or material characterised by a perceived, potential or real threat to human health or the environment or by a lack of published health standards”. A contaminant might also be emerging because of the discovery of a new source or a new pathway to humans. Currently, the USEPA lists 511 contaminants of known of emerging concern in biosolids. These range from endocrine disruptors which are associated with animal development disorders, estrogen-like compounds which interfere with animal fertility, to POPs such as flame retardants and detergents.

There is increasing global concern that these compounds, even at low concentration, may have a significant impact on the environment. Contaminants of known or emerging concern in biosolids come from many sources but are mostly generated from

- domestic use of personal care, pharmaceutical (including veterinary and recreational) and cleaning products which are used and washed away as wastewater, excreted, or disposed to sewer
- widespread commercial manufacture and use of chemicals in various industries that cannot be removed by on-site treatment but are discharged as liquid waste to sewer under trade waste agreements with local water authorities
- combining sewage sludges from other wastewater treatment plants that are not designed to remove the problematic contaminants
- management of runoff from roads and hard standing
- landfill leachate that ends up at wastewater treatment plants.

In 2019, about 85,000 dry tonnes of biosolids were generated in NSW with 90% applied to land. It is important for the EPA to be able to evaluate the potential environmental impacts of chemicals in NSW biosolids and have an approach for determining protective levels for human health and ecology where necessary. The following contaminants of known or emerging concern were identified as being likely to be in NSW biosolids and having properties that may pose a risk to the environment or human health. The EPA is carrying out further monitoring and assessment to determine whether regulation is appropriate.

5.8.1. Industrial chemicals and personal care products

These industrial chemicals were identified in the Contaminants Review and other literature sources as having a high priority for analysis in biosolids. The EPA is considering some of these chemicals in future sampling and analysis of biosolids.

Benzo(α)pyrene (BaP) (CAS No. 50-32-8)

BaP is the most toxic of a group of 16 chemicals known as polycyclic aromatic hydrocarbons (PAHs) and is a known carcinogen. PAHs are found naturally in coal, crude oil, and its products. They are also produced when fossil fuels, wood and tobacco are burned. Persistent in the environment, BaP will adsorb strongly to organic substrates including particulate material such as microplastics. BaP doesn't dissolve easily in water and is likely to accumulate in biosolids. In Europe, BaP content of biosolids compost varies from 1-6 mg/kg but has been reported as high as 30 mg/kg in Germany. There is very limited data in Australia about BaP in biosolids. In the 2017 EPA biosolids sampling campaign, the 95% UCL concentration for BaP was 0.35 mg/kg.

Di-2-ethylhexyl phthalate (DEHP) (CAS No. 117-81-7) and **Di-2-ethylhexyl adipate (DEHA)** (CAS No. 103-23-1)

A widespread industrial chemical, DEHP is not considered persistent in the environment but is a recognised endocrine disruptor and harmful to the male reproductive system. In industry, DEHP is a plasticiser used in the manufacture of PVC. It is present in many products such as shower curtains, garden hoses, swimming pool liners and food packaging.

DEHP is captured in the Waste Guidelines under "plasticiser compounds" where its concentration is added to another commonly occurring plasticiser, DEHA. Plasticiser compounds greater than 20 mg/kg are classified as restricted solid waste when leaching data is unavailable. It is noteworthy that during the 2017 EPA biosolids sampling campaign, the 95% UCL concentration for DEHP in biosolids was 25 mg/kg. DEHA has a lower toxicity than DEHP.

Phenol (non-halogenated) (CAS No. 108-95-2)

Phenol is an aromatic, volatile organic compound used in household cleaning products and is a measurable part in some Scotch whisky. It was reported in the Contaminants Review that up to 220 mg/kg of phenol has been identified in biosolids. The restricted solid waste threshold for phenol in the Waste Classification Guidelines without corresponding leaching data is 288 mg/kg.

Toluene (CAS No. 108-88-3)

Toluene is added to fuel, used to produce benzene and as a solvent in paints, synthetic fragrances, adhesives and cleaning agents. It is also used to make nylon, plastic bottles, cosmetics and polyurethanes. It was reported in the Contaminants Review that up to 737 mg/kg of phenol has been identified in biosolids. The restricted solid waste threshold for phenol without corresponding leaching data is 288 mg/kg.

Bisphenol A (BPA) (CAS No. 80-05-7)

BPA has been used as a plastic hardener for over 40 years. It is found in water bottles and canned food lining. The Australian and New Zealand Biosolids Partnership list BPA as a chemical that may pose a risk as an endocrine disrupting chemical. The Australian Industrial Chemicals Introduction Scheme categorise it as very toxic to fish and aquatic invertebrates with the ecological predicted no effect concentrations of 100 ng/L. Further, monitoring of Australian surface waters and STP effluent indicate that BPA is present at levels which are generally below 200 ng/L. However, seasonal variation of BPA emissions in urban rainwater runoff may contribute to higher concentrations of the chemical in surface waters near urban areas. The Contaminants Review assessed the concentration of BPA in biosolids to be up to 0.5 mg/kg. Note that this is not directly comparable to predicted no effect concentration values as several factors contribute to the final concentration in the environment once biosolids are applied to land.

Tonalide (CAS Nos. 1506-021 and 21145-77-7)

Tonalide has two CAS numbers because it's a mixture of two stereoisomers of the same chemical. It has a sweet musk odour and is used as a fragrance in cosmetics, detergents, fabric softeners and household cleaning products. It is categorised as persistent and toxic by the Australian Industrial Chemicals Introduction Scheme. Tonalide is expected to cause toxic effects at low concentrations in aquatic organisms across many trophic levels. The 95% UCL concentration for tonalide in the 2017 EPA biosolids campaign was 2.5 mg/kg.

5.8.2. Other chemicals

Many personal care products, as well as medical drugs used for human disease treatment, such as chemotherapy drugs, antibiotics, endocrine disruptors and other chemicals are discharged from domestic sewage systems to sewage treatment plants. Some of these pharmaceutical compounds are likely to be concentrated in biosolids. When biosolids are used for land application, it can take years for these contaminants to be removed from the environment and they can eventually end up in the food chain. The Contaminants Review flagged some as worthy of inclusion for testing in biosolids due to the lack of Australian biosolids data. Some of these chemicals were included for assessment in the biosolids sampling project.

Personal care products

Cashmeran (CAS No. 33704-61-9)

Decamethylcyclopentyl siloxane (CAS No. 141-63-9)

Octocrylene (CAS No. 6197-30-4)

DEET (CAS No. 134-62-3)

Octinoxate (CAS No. 5466-77-3)

Pharmaceuticals

Caffeine (CAS No. 58-08-2)

Ibuprofen (CAS No. 15687-27-1)

Naproxen (CAS No. 22204-53-1)

Paracetamol (CAS No. 103-90-2)

Aspirin (CAS No. 50-78-2)

Salicylic acid (CAS No. 69-72-7)

Diclofenac (CAS No. 15307-86-5)

Gemfibrozil (CAS No. 25812-30-0)

Fluoxetine (CAS No. 54910-89-3)

Amphetamine (CAS No. 300-62-9)

Opiates (CAS Nos. 561-27-3 and 50-36-2)

Estradiol (CAS No. 50-28-2)

Pathogens

6.1. Review of pathogens

In 2016, the EPA commissioned a comprehensive review of the Biosolids Guidelines, *Environmental Guidelines Use and Disposal of Biosolids Products – Pathogen Review* (the Pathogen Review*)*. The Pathogen Review focused on potentially pathogenic organisms in biosolids derived from STPs, their application to land in NSW and the associated risks to agriculture, human health, and the environment. The purpose of the Pathogen Review was to provide evidence-based recommendations to support decision-making and inform the regulatory position adopted by the EPA.

The Pathogen Review looked at the occurrence of pathogens in biosolids, both established and emerging pathogen reduction processes, and management practices in NSW that lower the risk posed by pathogenic organisms. It also considered current policies and practices in other jurisdictions and assessed their strengths and weaknesses. The Pathogen Review made the following recommendations to the EPA:

- Inclusion of protozoan parasites (*Cryptosporidium* and *Giardia*) as an additional pathogen group in the Biosolids Guidelines.
- Use and appropriate selection of indicator, reference, and index microorganisms. These will vary according to the intended use of biosolids and treatment process being verified. For most applications four microbial indicators were recommended to indicate the possible presence of (i) bacterial pathogens (*E.coli*), (ii) viral pathogens (Somatic coliphage), (iii) protozoan pathogens (*Clostridium perfringens*) and (iv) helminthic pathogens (total helminth ova). Similarly, for most applications five reference pathogens were recommended to represent (i) bacterial pathogens (*Salmonella*), (ii) viral pathogens (adenovirus), (iii) protozoan pathogens (*Cryptosporidium*), (iv) helminthic pathogens that are directly transmissible (*Ascaris*) and (v) helminthic pathogens that are transmissible via meat (*Taenia*). The helminths are included on a case-by-case basis depending upon catchment and intended use.
- Identification of high-risk sources of zoonotic or stock-infectious pathogens in each catchment to enable risk management and where necessary, notification.
- Making sure the pathogen management framework in revised Biosolids Guidelines is consistent with and links to national and NSW frameworks for the protection of animal health to protect grazing animals from exposure to certain pathogens.
- Use of microbial indicators and not microbial pathogens for routine monitoring because the routine assays associated with the latter are expensive, insensitive, and unreliable.
- Making sure there is a mechanism in the Biosolids Guidelines for validation of pathogen inactivation (hence rendering them incapable of infection) and removal (physically removing them) to allow production of biosolids from new or evolving treatment processes.
- Adding default scenarios that summarise, for given sources of biosolids and treatment processes meeting defined criteria, allowed uses and application restrictions. Default scenarios would particularly benefit smaller biosolids producers.
- Adoption of “Framework”, Hazard Analysis and Critical Control Points (HACCP) or ISO 22000 principles. These approaches define treatment and control processes, and critical limits for those processes that can be readily monitored, audited and regulated.
- Not placing undue reliance on point of use controls.
- Acceptance of case-specific fit-for-purpose approaches. The typical batch-test-release approach and alternatively the validation of pathogen $\log_{10}$ reductions through a specified treatment process should be allowed for. In both cases the use of quantitative microbial risk assessment (QMRA) should be recognised as a valid means of defining process requirements given specified intended uses and an agreed set of acceptable risk targets.

- Consideration of length of stockpiling to achieve stabilisation grade A following Victorian studies of pathogen inactivation in stockpiled, stored biosolids.
- Maintaining currency of guidelines.
- Other recommendations focus on clarifying definitions, setting criteria for suitable test methods, conducting further research, and removing unjustified inconsistencies between guidelines, particularly in neighbouring jurisdictions.

6.2. Quantitative microbial risk assessment (QMRA)

A proportion of pathogens present in wastewater are transferred to the sludge, and can persist through sludge and biosolids treatment and, unless controlled properly, may still be a risk to public health. In 2022 the EPA commissioned a quantitative microbial risk assessment (QMRA) to quantify the risk to human health associated with beneficial use of biosolids as a soil amendment. This was a screening level desktop study drawing on existing data and it built on the recommendations from the Pathogen Review above.

The Biosolids Guidelines rely on process train and end-product verification testing to make sure biosolids are fit-for-purpose. Finished product testing within a traditional verification framework has long been known to be inadequate for protection of public health from microbial agents. Limitations with sampling and the inability to analyse for all specific microbes of concern mean that consistent and timely safety cannot be ensured. As a result of this limitation, within the food and drinking water production systems, HACCP have been applied to make sure the final product is safe. Good management and control of the critical process conditions are the basis of making sure microbial safety targets are met. Finished product testing within this approach is a very specific and targeted approach to verification that compliments the overall safety framework. A HACCP framework has been recommended for controlling microbial risks associated with various fractions from wastewater, including sludge and biosolids, however this has not been implemented for biosolids in Australia.

The QMRA framework consists of four steps (WHO, 2016):

1. **Problem formulation:** the purpose and scope of the problem is defined. This scope includes the hazards to be considered, the exposure pathways and health endpoints. The EPA held a workshop with key stakeholders to define the range of end uses and exposure pathways relevant to NSW biosolids use. It is not exhaustive.
2. **Exposure assessment:** each component of the exposure pathway is quantified based on the best available scientific evidence.
3. **Health effects assessment:** the probability of infection, illness and subsequent health impacts are evaluated based on the best available scientific evidence.
4. **Risk characterisation:** the targets for the risk assessment are then quantified relying on the previous three steps.

Beginning with the concentration of individual pathogens in raw sewage, the fate, transport and persistence through the sewage and sludge treatment processes are quantified. This approach allows for the concentration of pathogens in the finished product to be linked to the operational conditions (e.g. residence time, temperature, pH) of the treatment processes. Depending on the end-use and associated estimated exposure to biosolids, the probability of infection and illness can be quantified and compared with the health outcome target. Treatment and exposure controls needed to achieve safety can then be quantified in terms of Log_{10} reduction (**LRV**) in pathogen concentration. Within this framework, based on any defined end-use application, the required treatment targets (LRV) can be defined to ensure safety.

Reference pathogens representing bacteria (*Salmonella* and *Campylobacter*), viruses (Adenovirus), protozoa (*Cryptosporidium* and *Giardia*), and helminths (*Ascaris* for directly transmissible and *Taenia* for indirectly transmissible) were selected.

Exposure pathways focused on human exposure and subsequent health risks from biosolids application in agriculture (pasture for grazing, food crops), mine site rehabilitation, public green space, residential use, drinking water catchment areas and composting with garden waste. Points in each exposure pathway were identified where people may be exposed to the biosolid product.

The first step in applying the QMRA framework is to quantify the concentration of each reference pathogen in untreated sewage. Default estimates from Australian and international guidelines as well as local data supplied by Sydney Water were considered. Pathogen concentrations in raw sludge were then estimated by numerical modelling which accounts for partitioning of pathogens between solids and effluent as well as inactivation of pathogens during treatment.

The health impact assessment involved analysing dose response models and determining the probability of illness given infection.

For risk characterisation two separate metrics were quantified for each exposure pathway:

1. the critical pathogen concentration and
2. the treatment target (LRV).

The critical pathogen concentration is the concentration of reference pathogen in biosolids at the point of exposure for a particular exposure pathway that equates to an annual health risk of 1×10^{-6} disability adjusted life year (often referred to as DALY). The disability adjusted life year was selected to be the metric for the health outcome. The disability adjusted life year is recommended by the World Health Organisation and allows for different durations and severities of illness to be accounted for in determining safety. In the context of public health where negligible risk is expected (e.g., drinking water) the disability adjusted life year target for defining safety is 1×10^{-6} per person per year.

The treatment target is defined as the required Log_{10} reduction from raw sludge to exposure to achieve safety (i.e. $1{\times}10^{-6}$ disability adjusted life year per person per year). The required Log_{10} reduction is also referred to as the log reduction value and is a measure to quantify pathogen reduction during sewage treatment (1 log reduction value = 90% reduction, 2 log reduction value = 99% reduction etc). The objective of the QMRA model was to define the treatment requirements (log reduction value) to achieve safety from the point of raw sludge to end-use.

The very low concentrations needed to achieve safety against the 1×10^{-6} disability adjusted life year benchmark (in the absence of all other controls) means that end product testing to verify these low levels of pathogens is not practical.

Controls for managing health risk by reducing pathogen concentration (and ultimately exposure) include combinations of sludge treatment such as anaerobic and aerobic digestion, biosolids treatment (e.g. composting), environmental controls (e.g. incorporation with soil, inactivation with time and exposure to sunlight), and reducing exposure through access restrictions. Each of these controls has an associated log reduction value which must be determined to put the HACCP framework in place. At present there is a lack of information available to quantify the log reduction values.

The primary benefits of the QMRA are that a wide range of end use practises can be considered, relying on operational verification to make sure public health safety.

6.2.1. Conclusions and recommendations of the QMRA

The approach for implementing a QMRA in place for defining health-based performance targets for the safe reuse of biosolids products was demonstrated. The QMRA made the following recommendations:

Combinations of treatment and controls can be applied that are specifically relevant to the local context to achieve safety. This will deliver a framework intended to be flexible, with biosolids products tailored to be fit for purpose. The objective is to ensure public health safety, while at the same time preventing over-design of treatment, or unnecessarily restrictive controls.

Uncertainty and sensitivity analysis of the current model

The quantitative treatment targets here are a first pass for illustration of the approach. It is recommended that further work be undertaken to refine the results including to

- assess the importance of locally relevant values for pathogen concentration in biosolids, especially for small and regional communities
- review the fate and transport of pathogens during wastewater and sludge treatment including the parameters used in the model for quantifying pathogen concentration in raw sludge
- assess the importance of the magnitude and frequency of exposure to biosolids
- assess the importance of model defaults including dose-response models and point estimates of probability of illness.

Recommendation 1: Undertake a sensitivity analysis of the current model to assess the importance of uncertainties in model inputs and identify any critical data gaps.

Quantify pathogen concentration in sludge and biosolids

Quantifying the concentration of appropriate reference pathogens in raw and treated sewage sludge is a considerable challenge and there is limited data of relevance to NSW (both city and regional). Recent data from Sydney Water summarised in this report shows the variability in concentration for different pathogens. Importantly, the high concentration of human enteric viruses, not only in raw sludge but also potentially in biosolids products, needs further investigation. While some pathogens may be identified by analytical methods, some methods are unable to indicate whether those organisms are in an infectious state. In defining health-based treatment targets, consideration must focus on infectious pathogens and seek to eliminate from the calculation those microorganisms that have been inactivated.

Recommendation 2: Support and (when possible) initiate targeted data collection programs that focus on quantifying the magnitude and variability of infectious pathogens in sewage, raw sludge and biosolids products for all of NSW.

Quantify pathogen log reduction values for sludge and biosolids treatment processes

The performance of various sludge and biosolids treatment processes for inactivation of pathogens is poorly understood. Linking achievable log reduction values to measurable process conditions such as residence time and temperature, is essential for the practical implementation of the framework, however this data currently does not exist.

Recommendation 3a: Undertake a targeted and quantitative literature review of published log reduction values for pathogens and indicators for all processes and controls. Log reduction values should be directly linked to measurable process variables from the reviewed publication.

Recommendation 3b: Support and (when possible) initiate targeted data collection programs that focus on quantifying the log reduction values of sludge and biosolids treatment processes. Such programs should focus on pathogen inactivation mechanisms and link reduction to measurable process variables.

Continue to consult on the scope of exposure pathways

The exposure pathways quantified in this project were identified by stakeholders who participated in problem formulation. Further work is needed to make sure the scope of exposures is appropriate to the NSW context, including any vulnerable groups that may need consideration.

Recommendation 4: Continue consultation as broadly as possible with respect to exposure pathways to be considered in any biosolids regulatory approach. Consideration should be given to the needs of any vulnerable groups, especially Aboriginal communities.

Recommendation 5. Develop a roadmap for implementation in consultation with the wastewater industry. Identify all the key industry engagement tasks and supporting documentation required to achieve successful implementation. Undertaking this process in collaboration with industry will enable the EPA to benefit from and build on the learnings of this closely aligned sector.

Stability and odour management

7.1. Review of stability

In 2016, the EPA commissioned a comprehensive review of the Biosolids Guidelines focusing on stability, *Assessment and management of material stability in contemporary Environmental Guidelines for the Use and Disposal of Biosolids Products* (the Stability Review). The purpose of this was to summarise the current knowledge on biosolids stability and provide evidence-based recommendations to support decision-making and to help inform the regulatory position adopted by the EPA.

Primary aims of the Stability Review were to determine what are "stable" biosolids, the suitability of the existing measuring methods to measure it, and to understand the link between biosolids stability and odour. Policies and practices in other jurisdictions were compared with those in NSW.

There is no universal definition of stability; stabilisation being the irreversible changes associated with the processing of raw sludge to transform the organic matter and reduce putrefaction (which causes odours). Aerobic digestion, anaerobic digestion and composting can be considered as true stabilisation processes. Other processes such as adding lime and thermal drying remove pathogens but do not create a fully stabilised product which has major implications for further transport and processing.

The Biosolids Guidelines need all biosolids destined for land application to be classified. Classification is a combination of the contaminant grade and the stabilisation grade. The stabilisation grade (A, B or C) is determined based on both pathogen reduction and vector attraction reduction needs. Most biosolids produced in NSW are stabilisation Grade B.

The Stability Review found that:

- when NSW was compared with international jurisdictions, "the single most relevant finding in relation to stability is the lack of a 'best practice manual' for the management of biosolids in NSW". This could include a range of process recommendations to make sure a stable product or could take the form of a risk-based management tool such as HACCP, which could also be used to manage the risks associated with pathogens and contaminants.
- the vector attraction reduction protocols in the guidelines are relevant to pathogen reduction but do not guarantee the biosolids will be free of offensive odours. They need to be complemented with better operational process controls and additional or new measurements need to be considered to determine the 'stability' of biosolids.
- for irreversible stabilisation processes such as anaerobic and aerobic digestion, minimum sludge retention times should be given in the guidelines to reduce the risk of nuisance odours
- assessment of stability should be done after dewatering, transport and storage as these practices may have adverse effects on stabilisation.
- for reversible stabilisation processes such as liming addition and thermal drying, they should be considered as non-stabilisation processes that have an important role to play in emergency disposal.
- odours are produced from organic matter breaking down. Current stabilisation guidelines have been developed to satisfy microbial and vector attraction reduction needs and more stabilisation may be needed to meet acceptable odour levels. A combination of different types of methods to evaluate odour quality could be used at different stages of processing.
- an answer to the concept of defining "stability" may be use of a risk management framework such as HACCP. The Australian Drinking Water Guidelines incorporates risk management features and could be seen as a model for new biosolids guidelines.
- stability in biosolids may be defined as *an irreversible and consistent low rate of biological activity achieved* after enough processing of sewage sludge.

Management Controls

The EPA considered the requirements in Section 4 of the Biosolids Guidelines relating to the land application site and what management controls are appropriate to allow beneficial land application with minimal impact to the surrounding environment and community. These controls include soil characteristics, exclusion/withholding periods, and buffer zones to protect sensitive sites from any impacts of biosolid use.

The EPA reviewed scientific literature and guidelines and compared approaches in local and international jurisdictions with the NSW requirements. In some cases, NSW has greater restrictions, such as the current five-year withholding period for crops grown below the surface (e.g. potatoes and carrots). A similar restriction in Victoria is three years.

No robust evidence was found to change current requirements. **The EPA is proposing to consider which controls are mandatory and the regulatory tools needed to make sure best practice as part of its regulatory review.**

Microplastics

9.1. Review of microplastics

Contaminant plastics less than 5 mm have been termed ‘microplastics’. These are physical contaminants which accumulate over time and may interfere with biological processes and ecosystems. Plastics physically degrade into smaller and smaller fragments over time and have been measured in the nanometre range (<0.001 mm), small enough to cross biological barriers.

Microplastics have been measured in human blood, can cross the blood brain barrier, and have been found in the placenta. Plastics contain many additives which are known to be carcinogenic and can leach over time. Microplastics can adsorb and desorb chemical contaminants such as PFAS. Their surface area is colonised by bacteria to form a ‘biofilm’ which enables transport of pathogens, and which can facilitate transfer of anti-microbial resistant genes. Research suggests risks to ecosystems and human health are not the same but differ across microplastic particle size, morphology, colour, additives, and polymer type.

Microplastics enter the natural environment in many ways. Regarding activities regulated by the EPA, a pathway of concern is the beneficial land application of recovered wastes, including biosolids. Sewage treatment plants (STPs) are a significant source of microplastics entering the environment and almost all microplastic particles which enter STPs are captured in the biosolids produced during effluent treatment. It is estimated that biosolids applied to land results in the deposition of 4,700 tonnes of microplastic particles to the Australian environment annually (Okoffo et al., 2020). Of this, 3,700 tonnes are released to agriculture and 140 tonnes to landscape topsoil.

Microplastic exposure is increasing exponentially, while the impacts of microplastics on human and environmental health over the long-term remain unknown. Regulatory agencies globally are beginning to investigate and take action on microplastics. In NSW, voluntary action has phased out a significant portion of microbeads in rinse-off personal care products. From 1 November 2022 the *Plastic Reduction and Circular Economy Act 2021* banned the supply of rinse-off personal care products containing microbeads.

At present, microplastics are not regulated in biosolids in NSW (or elsewhere), although flexible and rigid plastic particles between 2 and 5 mm are regulated in composts. Recent developments in observational analytical methods are driving research to measure these particles in water, blood and complex organic matrices (soil, biosolids and compost).

9.2. CSIRO study

The EPA commissioned the CSIRO to quantify microplastics in wastewater influent and effluent and determine the hazard associated with their release into marine environments. The report was titled *Microplastic quantification in wastewater: Wastewater influent and effluent trends over a 10 month period* (the Microplastic Study). While the primary focus of this study was on effluent and marine environments, a once off assessment was also carried out on biosolids from seven STPs in Sydney.

The results were used to

a. assess how effective the voluntary industry agreement to phase out microbeads was
b. compare the effect of wastewater treatment methods for the removal of microplastics between primary treatment and tertiary treatment STPs over 10 months
c. assess the removal of microplastics from wastewater into biosolids during wastewater treatment and their transfer to terrestrial environments
d. estimate how much contamination was released into marine environments and how this impacts marine organisms.

Study results of the marine environment have not been included here. Results of importance to biosolids are summarised below.

- Tertiary treatment STPs are estimated to be discharging between 86 million to 350 million microplastic particles each day and that the primary plants are discharging between 5.4 billion to 120 billion microplastic particles each day into the marine environment.
- Spherical microbeads from personal care products were infrequently detected in wastewater. When they were, between 1-3 microbeads per litre were measured in influent from both types of plants.
- At primary treatment STPs, removal of microplastics during wastewater treatment* ranged from very little to a large fraction (0- 79%) through primary (screening and settling) treatment, while the tertiary treatment STP removed more than 98% of microplastics through tertiary (primary treatment plus biological treatment and disinfection) treatment.[8]
- Most microplastic particles in all biosolid samples were fragments and the loads ranged from 45,000 to 323,000 microplastics/kg, consistent with international studies (typically 3,373 to 187,000 microplastics/kg).
- An assessment of three common wastewater contaminants (benzalkonium chloride, bisphenol A and triclosan) indicated they were strongly bound to polyethylene (PE) and polyethylene terephthalate (PET) microplastics.

The study concluded that:

- the tertiary treatment STP was more effective at removing microplastics from wastewater than the primary treatment STP. The primary treatment process includes removal of particulates through screening, surface skimming and sedimentation. The tertiary wastewater treatment includes primary treatment plus biological digestion of nutrients and particulates and UV disinfection prior to release of effluent.
- the concentrations of microplastics in biosolids from STPs, although very high, are unlikely to adversely impact terrestrial organisms based on existing evidence related to terrestrial effects assessments. The amount of microplastics, however, may increase over time in soils through ongoing biosolid application and microplastic accumulation. The potential impact needs to be balanced against the many benefits of biosolids reuse for soil improvement (e.g. carbon emission reductions, reduced use of synthetic fertilisers).

The EPA is proposing to develop and approve methods for the analysis of microplastics in biosolids and more broadly other recovered wastes, and begin a program of testing to understand microplastics load and potential impact on human health and the environment. This work may inform future regulation of microplastics in biosolids.

[8] removal of microplastics during wastewater treatment means removal from effluent. Therefore, up to 98 % removal of microplastic particles at Cronulla means that 98 % of microplastic particles in the influent are partitioned to the biosolids, and only 2% remain in the effluent

References

Deere, D., Billington, K., O'Connor, N. and Stevens, D. 2017. Environmental Guidelines Use and Disposal of Biosolids Products – Pathogen Review. Final Report produced for NSW EPA by Water Futures Pty Ltd

Fisher, R., Hayes, J., Roser, D., Alvarez Gaitan, J.P, and Stuetz, R. 2017. Assessment and management of material stability in contemporary Environmental Guidelines for the Use and Disposal of Biosolids Products. UNSW Water Research Centre

HEPA 2022, Draft PFAS National Environmental Management Plan Version 3.0*,* Heads of EPA Australia and New Zealand 2022. CC BY 4.0

HEPA 2022, PFAS NEMP Supporting Document - Derivation of biosolids criteria (restricted and unrestricted use) and maximum allowable soil contaminant concentrations for PFOS, PFHxS and PFOA, CC BY 4.0. Heads of EPA Australia and New Zealand

National Geochemical Survey of Australia. https://www.ga.gov.au/about/projects/resources/national-geochemical-survey

NSW Department of Planning and Environment, Environment and Heritage Group 2023. NSW Biosolids Guideline Review: Identification of key exposure pathways to assess risks from PFAS in biosolids.

NSW Department of Planning and Environment, Environment and Heritage Group 2023. NSW Biosolids Guideline Review: Identification of key exposure pathways to assess risks from HHCB, triclosan, chlordane and PBDEs in biosolids.

NSW Department of Planning and Environment, Environment and Heritage Group 2023. *NSW* Biosolids Guideline Review: Threshold derivation for contaminants in biosolids – PFAS, HHCB, triclosan, PBDEs and chlordane.

NSW Environment Protection Authority. 2022. Report on the survey of NSW Sewage Treatment Plants (STPs) in relation to biosolids production

Okoffo, E.D., Tscharke, B.J., O'Brien, J.W., O'Brien, S., Ribeiro, F., Burrows, S.D., Choi, P.M., Wang, X., Mueller, J.F., Thomas, K.V. 2020. Release of microplastics to Australian land from biosolids end-use. Environmental Science and Technology 54 (23), 15132-15141.

Petterson, S. 2022. QMRA to inform the approach for regulating pathogens as part of the NSW Biosolids Guidelines Review. Water & Health Pty Ltd

Shaw, J.L.A, Ernakovich, J.G., Judy, J.D., Farrell, M., Whatmuff, M., Kirby, J. 2020 Long-term effects of copper exposure to agricultural soil function and microbial community structure at a controlled and experimental field site. Environmental Pollution 263: 114411

WCA Environment Ltd. 2016. Environmental Guidelines: Use and disposal of biosolids products – Contaminant Review

WHO 2016. Quantitative Microbial Risk Assessment for Water Safety Management, World Health Organization, Geneva

Williams, M., Pham, K., Mulder, R., Pring, N., Hickey, M., and Mardel, J., 2020. Microplastic quantification in wastewater: Wastewater influent and effluent trends over a 10 month period. CSIRO, Australia