PFAS NEMP Supporting Document

Human health soil guideline values for PFOS + PFHxS and PFOA: Derivation of the human health investigation levels for soil for 'residential with garden/accessible soil' (HIL A) and a review of relevant soil to plant transfer factors

National Chemicals Working Group of the Heads of EPAs Australia and New Zealand

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Acknowledgement of Country

We acknowledge the Traditional Custodians of Australia and their continuing connection to land and sea, waters, environment and community. We pay our respects to the Traditional Custodians of the lands we live and work on, their culture, and their Elders past and present.

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Introduction

This information supporting paper presents information on the derivation of the human health soil guideline values (GVs) for PFAS for the land use scenario 'residential with garden/accessible soil', which are adopted and published in the PFAS National Environmental Management Plan (NEMP) 3.0. These GVs were derived using a methodology consistent with assumptions set out in the ASC NEPM for the health investigation levels (HILs). Note these values have not been derived under the ASC NEPM.

This document also provides a summary of the soil to plant transfer factors (TFs) extracted during a literature review. This information is intended to support risk assessments for PFAS investigations where specific scenarios may need to be considered.

Background

At the request of Environment Ministers around Australia, the Heads of EPAs Australia, and New Zealand (HEPA) and the Australian Government Department of Climate Change, Energy, the Environment and Water (DCCEEW) collaborated to develop and publish the PFAS NEMP (NEMP 1.0 in February 2018, NEMP 2.0 in January 2020 and draft NEMP 3.0 in August 2022).

The NEMP provides a nationally consistent approach to environmental management of PFAS. Included in the NEMP are human health soil GVs, derived using a methodology consistent with assumptions set out in the ASC NEPM for the HILs. The HILs are designed to be protective of human health under different land use scenarios, including:

- Residential with garden/accessible soil (HIL A)
- Residential with minimal opportunities for soil access (HIL B)
- Public open space (HIL C)
- Industrial/ commercial (HIL D).

For PFAS, the most sensitive pathway is that for the HIL A because of the potential for human exposure through PFAS uptake into edible plants from soil, and therefore the HIL A is the focus of this document. The PFAS considered in this document are the sum of PFOS and PFHxS (expressed as PFOS + PFHxS) and PFOA.

This work has been undertaken over several stages. HIL A values for PFOS + PFHxS and PFOA were published in the NEMP 2.0, for which the supporting information was presented in OEH (2019). As part of this work, a key data gap identified was the limited information on soil to plant TFs for PFOA. Therefore, in 2021 a review of available data was conducted to determine if the HIL A value listed for PFOA in NEMP 2.0 is appropriate. After the review of new information, it was concluded that the HIL A soil guidance values listed in NEMP 2.0 are appropriate and have been retained in NEMP 3.0 (see Table 1).

Table 1 Human health HIL A soil guideline values adopted in PFAS NEMP 3.0

Category	HIL A (10% home produce consumed)	HIL A (50% home produce consumed)
Sum of PFOS and PFHxS	0.01 mg/kg	0.002 mg/kg
PFOA	0.1 mg/kg	0.02 mg/kg

Note: The standard methodology under the ASC NEPM HIL A considers two exposure pathways: direct exposure to contaminated soil and dust, and indirect exposure from the consumption of home-grown fruit or vegetables. The default assumption is that home-grown produce makes up 10% of fruit and vegetables consumed. Note these criteria do not account for potential home consumption of eggs from home -raised poultry, nor of milk or meat from stock on the premises. These soil guidance values only consider exposure routs through soil contact. They should be applied in conjunction with other lines of investigation to account for potential leaching, off-site transport, bioaccumulation and secondary exposure.

The HIL A are based on calculations considering a chemcial intake from a contaminated source equal to 20% of the tolerable daily intakes (TDI). In other words, this allows for 80% of of the chemical intake to be attributed to other exposure pathways. This means that exceeding these values may not constitute a risk if other pathways are controlled.

A review of soil to plant transfer factors for PFOS and PFHxS has shown that PFHxS accumulates more readily in plants compared with PFOS. This influences the total PFOS plus PFHxS concentration predicted in the plant. The combined PFOS+ PFHxS HIL A criteria was derived assuming that PFOS and PFHxS are present in a soil at equal proportions. If a site has significantly more PFHxS in the soil than PFOS, the concentrations of total PFOS plus PFHxS in the plant will be higher than if they were present in equal proportions. In such a case, a re-calculation of the criterion based on site-specific conditions is recommended as the HIL A soil criteria may not be protective in such instances.

Scope

The following sections present the background information on the:

- Derivation of the HIL A adopted in NEMP 3.0
- Soil to plant transfer factors used in deriving the HIL A
- Summary of soil to plant transfer factors for other plant categories not included in ASC NEPM ; i.e. plant parts or types of plants beyond the ASC NEPM categories of green vegetables, root vegetables, tuber vegetables and tree fruits.

This document includes details on the assumptions used in deriving the HIL A for PFOS + PFHxS and PFOA, as well as the nationally endorsed TFs and the rationale for their use. These values can be used for assessing risk for site specific assessments and adjusted scenarios where appropriate.

Further information on the approach and selection of TFs and a sensitivity analysis using different types of data are included in the appendices.

1 Derivation of the HIL A adopted in NEMP 3.0

The human health-based soil guideline values for the HIL A were derived according to the methods published under the ASC NEPM (NEPC 2013) for which two pathways of exposure are considered:

- direct exposure to contaminated soil
- indirect exposure from consumption of home-grown fruit and / or vegetables grown in contaminated soil.

Criteria for bioaccumulative contaminants such as PFAS are calculated using soil to plant TFs, which estimate the concentration of a contaminant in plant tissue based on the soil concentration of that contaminant. Soil criteria were calculated using the HILs Calculator Microsoft Excel spreadsheet provided on the National Environment Protection Council (NEPC) website (accessed 2021). Input parameters were consistent with guidance provided in the ASC NEPM (NEPC 2013).

For residential with garden / accessible soil, the standard methodology under the ASC NEPM HIL A assumes that home-grown produce makes up 10% of fruit and vegetables consumed. In the PFAS NEMP, an example for 50% of chemical exposure through consumption of home-grown produce is also included as an additional scenario. Note these criteria do not account for potential consumption of eggs from home-raised poultry, nor of milk or meat from stock on the premises. However, the HILs calculations consider a chemical intake from a contaminated source equal to 20% of the tolerable daily intake (TDI). In other words, this allows for 80% of the chemical intake to be attributed to other exposure pathways (e.g. consumption of other home grown produce, poultry eggs and recreational activities) as well as background exposure. This means that exceeding these values does not constitute a risk if other pathways are controlled.

2 Soil to plant transfer factors used to derive the HIL A

To derive the HIL A values listed in Table 1, concentrations in fruit and vegetables are calculated using soil to plant TFs. The method used to calculate the TFs are discussed in Section 2.1 below. The final TFs used in the HIL A derivation are summarised in Table 2 and include four plant categories: green vegetables, root vegetables, tuber vegetables, and tree fruit (based on ASC NEPM). A summary of the studies from which these final TFs were derived are presented in Appendix A. Additionally, a sensitivity analysis was conducted using different data points with varying TFs to inform how this may influence the guideline values, and this is presented in Appendix B.

Table 2 Soil to plant transfer factors used in the calculations for PFOS + PFHxS and PFOA guideline values for residential with garden / accessible soil (HIL A)

	Category	Species	Data source	Final TF
Sum of PFOS and PFHxS [a]	Green vegetables	Celery	Blaine et al. 2014	0.79
	Root vegetables	Radish	Lasee et al. 2019	0.58
	Tuber vegetables	Potato	Lechner & Knapp 2011	0.20
	Fruit	Tomato	Bao et al. 2020	0.06
PFOA	Green vegetables	Chicory	Gredelj et al. 2020	0.14
	Root vegetables	Radish	Lasee et al. 2019	0.93
	Tuber vegetables	Potato	Lechner & Knapp 2011	0.03
	Fruit	Tomato	Bao et al. 2020	0.039

Notes

[a] TFs for PFOS + PFHxS have been calculated using the geometric mean of limited data for PFHxS TFs as a multiplier to 'correct' PFOS TFs, and assuming 50:50 proportions of PFOS and PFHxS concentrations (for further information see Appendix A).

2.1 Calulating Transfer Factors

The soil to plant TFs are calculated according to Equation 1. For calculating the TFs, wet weight TFs were used. Where data were not available to directly calculate wet weight TFs, dry weight TFs were converted to wet weight TFs using literature values for plant moisture contents (Equation 2).

Equation 1

$$TF = \frac{C_{plant}}{C_{soil}}$$

where:

C_{plant} = concentration of PFOS or PFOA in wet weight of plant

C_{soil} = concentration of PFOS or PFOA in dry weight of soil

Equation 2

$$C_{plant} = C_{plant\ .dry} \times (\frac{100 - MC}{100})$$

where:

$C_{plant.dry}$ = concentration of PFOS or PFOA in plant on a dry weight basis

MC = moisture content of raw plant

3 Summary of TFs for other plant categories not included in ASC NEPM

As part of the reviews conducted to assess TFs for PFOS, PFHxS and PFOA, information on plant types and plant compartments not relevant to the ASC NEPM categories were also identified from the assessed papers. This section provides a summary of TFs from the literature beyond the ASC NEPM plant categories. Note this is not intended as a systematic comprehensive literature review but is a summary of available literature reviewed in the work undertaken by the NCWG to date. This can be drawn on by practitioners for site assessment and scenario specific purposes, where relevant. TFs for PFHxS are listed in Appendix A.

Table 3 PFOS soil to plant transfer factors, for plant categories not included in the ASC NEPM calculations, calculated from data in the listed data sources.

Group	Plant	PFOS TF	Claculation basis	Data source
		(mg/kg$_{plant}$)/(mg/kg$_{soil}$)	**Plant DW or WW** [a]	
Vegetative parts DW	Alfalfa	0.4	DW	Wen et al. 2016
	Alfalfa	0.06 – 1.6	DW	Brignole et al. 2003
	Alfalfa	1.4	DW	Lasee et al. 2019
	Carrot	1.4 – 2.1	DW	Bizkarguenaga et al. 2016
	Carrot	23	DW	Lasee et al. 2019
	Cucumber	0.05 – 0.5	DW	Moshfeghi 2015
	Flax	0.9 – 1.3	DW	Brignole et al. 2003
	Maize	0.1 – 0.2	DW	Stahl et al. 2009
	Maize	0.2	DW	Wen et al. 2016
	Mung bean	0.7	DW	Wen et al. 2016
	Oats (straw)	0.2 – 0.8	DW	Stahl et al. 2009
	Onion	0.7	DW	Brignole et al. 2003
	Radish	0.5	DW	Wen et al. 2016
	Radish	10	DW	Lasee et al. 2019
	Ryegrass	0.2	DW	Wen et al. 2016
	Soybean	0.3	DW	Wen et al. 2016
	Soybean	0.4 – 4.1	DW	Brignole et al. 2003
	Tomato	0.8 – 2.2	DW	Brignole et al. 2003
	Wheat	0.2 – 1.5	DW	Stahl et al. 2009
	Wheat (straw)	0.2 – 0.3	DW	Wen et al. 2014
	Wheat	0.1 – 0.5	DW	Zhao et al. 2014

Group	Plant	PFOS TF	Claculation basis	Data source
		(mg/kg_{plant})/(mg/kg_{soil})	**Plant DW or WW** [a]	
Vegetative parts WW	Carrot	0.3 – 0.4	WW	Lechner & Knapp 2011
	Cucumber	0.1 – 0.2	WW	Lechner & Knapp 2011
	Potato	0.3 – 0.4	WW	Lechner & Knapp 2011
	Wheat grass	0.2	WW	Bräunig et al. 2018
Roots	Alfalfa	3.1	DW	Wen et al. 2016
	Alfalfa	4.3	DW	Lasee et al. 2019
	Lettuce	3.9	DW	Wen et al. 2016
	Maize	2.7	DW	Wen et al. 2016
	Mung bean	4.2	DW	Wen et al. 2016
	Ryegrass	1.4	DW	Wen et al. 2016
	Soybean	4.7	DW	Wen et al. 2016
	Wheat	1.2 – 1.6	DW	Wen et al. 2014
	Wheat	0.9 – 2.1	DW	Zhao et al. 2014
Grains	Flax	0.04 – 0.09	DW	Brignole et al. 2003
	Oats	0.002 – 0.02	DW	Stahl et al. 2009
	Maize	<LOD – 0.008	DW	Stahl et al. 2009
	Wheat	<LOD – 0.0007	DW	Stahl et al. 2009
	Wheat	0.06 – 0.08	DW	Wen et al. 2014
Legumes	Soybean	0.02 – 0.4	DW	Brignole et al. 2003

Notes

[a] DW = dry weight; WW = wet weight.

LOD refers to the limit of detection

These tables are not exhaustive lists of the available literature.

Table 4 PFOA soil to plant transfer factors, for plant categories not included in the ASC NEPM calculations, calculated from data in the listed data sources.

Group	Plant	PFOA TF	Claculation basis	Data source
		(mg/kg_{plant})/(mg/kg_{soil})	**Plant DW or WW** [a]	
Vegetative parts DW	Alfalfa	3.2	DW	Wen et al. 2016
	Alfalfa	10	DW	Lasee et al. 2019
	Carrot	1.1 – 3.1	DW	Bizkarguenaga et al. 2016
	Carrot	54	DW	Lasee et al. 2019
	Cucumber	0.2 – 0.4	DW	Moshfeghi 2015
	Maize	0.1 – 0.3	DW	Stahl et al. 2009

Group	Plant	PFOA TF	Claculation basis	Data source
		(mg/kg_{plant})/(mg/kg_{soil})	**Plant DW or WW** [a]	
	Maize	0.2	DW	Wen et al. 2016
	Mung bean	8.4	DW	Wen et al. 2016
	Oats	0.2 - 4.3	DW	Stahl et al. 2009
	Radish	5.3	DW	Wen et al. 2016
	Radish	47	DW	Lasee et al. 2019
	Ryegrass	1.3	DW	Wen et al. 2016
	Soybean	0.3	DW	Wen et al. 2016
	Wheat	1.9 – 6.8	DW	Stahl et al. 2009
	Wheat	0.7 – 1.5	DW	Wen et al. 2014
	Wheat	0.09 -0.3	DW	Zhao et al. 2014
Vegetative parts WW	Carrot	0.5	WW	Lechner & Knapp 2011
	Cucumber	0.8 – 1.0	WW	Lechner & Knapp 2011
	Potato	0.4	WW	Lechner & Knapp 2011
	Wheat grass	0.6	WW	Bräunig et al. 2018
Roots	Alfalfa	10.3	DW	Wen et al. 2016
	Alfalfa	19	DW	Lasee et al. 2019
	Lettuce	6.1	DW	Wen et al. 2016
	Maize	1.7	DW	Wen et al. 2016
	Mung bean	7.8	DW	Wen et al. 2016
	Ryegrass	2.4	DW	Wen et al. 2016
	Soybean	3.2	DW	Wen et al. 2016
	Wheat	1.7 – 4.9	DW	Wen et al. 2014
	Wheat	1.1 – 2.3	DW	Zhao et al. 2014
Grains	Oats	0.03 – 0.1	DW	Stahl et al. 2009
	Maize	0.003 – 0.009	DW	Stahl et al. 2009
	Wheat	0.009 – 0.1	DW	Stahl et al. 2009
	Wheat	0.1 – 0.2	DW	Wen et al. 2014

Notes

[a] DW = dry weight; WW = wet weight.

These tables are not exhaustive lists of the available literature.

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Appendix A : Summary of transfer factors considered for deriving the HIL A

The TFs summarised in Tables 2 to 4 show there is considerable variation in TFs for the same plant species. This variation in part is due to variability from different soil types used in the studies and also in some instances dependence on soil concentration, where higher soil concentrations result in lower TFs. This finding supports the use of the maximum TF for each plant category, rather than using the mean or median, which would underestimate plant concentrations in sandier soils and/or less contaminated soils.

The sections below provide a summary on the TFs considered when deriving the HIL A criteria for PFAS.

A.1 PFOS + PFHxS

PFOS TFs

For PFOS a total of 16 relevant publications were identified and used to derive the soil screening criteria published in NEMP 2.0 (refer to OEH 2019). An additional 3 relevant publications were added as part of the this review undertaken in 2021 to determine if the HIL A value listed for PFOA in NEMP 2.0 is appropriate (see information in Background chapter, section on PFOA below and Appendix B). TFs assessed for PFOS are summarised in Table A1. The maximum TF for each category was selected for deriving the soil criterion.

Table A1 PFOS soil to plant transfer factors for ASC NEPM plant categories, calculated from data in the listed data sources.

Group	Plant	PFOS TF	Calculation basis	Data source	% moisture content [a]	Max. TF adjusted to WW
		mg/kg_{plant} / mg/kg_{soil}				
Green Vegetable	**Celery**	**1.4**	**DW**	**Blaine et al. 2014**	**86***	**0.20**
	Lettuce	0.1 – 0.2	DW	Bizkarguenaga et al. 2016	96	0.01
	Lettuce	0.1 – 1.7	DW	Blaine et al. 2013	96	0.07
	Lettuce	0.7 – 2.2	DW	Brignole et al. 2003	96	0.09
	Lettuce	0.4	DW	Wen et al. 2016	96	0.02
	Onion	0.8 – 1.4	DW	Brignole et al. 2003	90	0.14
	Chicory head[b]	1.2 – 2	DW	Gredelj et al. 2020	92	0.16
	Chicory shoot[b]	1.1 – 1.5	DW	Gredelj et al. 2020	92	0.12

Group	Plant	PFOS TF	Calculation basis	Data source	% moisture content [a]	Max. TF adjusted to WW
		mg/kg_{plant} / mg/kg_{soil}				
Root vegetable						
	Radish[b]	**2.9**	**DW**	**Lasee et al, 2019**	**95**	**0.15**
	Radish	2.6	DW	Wen et al. 2016	95	0.13
	Radish	0.07 - 0.7	DW	Blaine et al. 2014	90*	0.07
	Carrot	1.0	DW	Lasee et al, 2019	88	0.13
	Peeled carrot	0.4 – 0.6	DW	Bizkarguenaga et al. 2016	88	0.07
	Peeled carrot	0.04 – 0.05	WW	Lechner & Knapp 2011	NR	0.05
	Carrot peel	0.4 – 05	DW	Bizkarguenaga et al. 2016	88	0.06
	Carrot peel	0.03 – 0.04	WW	Lechner & Knapp 2011	NR	0.04
Tuber vegetable	**Potato peel**	**0.01 – 0.05**	**WW**	**Lechner & Knapp 2011**	**NR**	**0.05**
	Peeled potato	0.0006 – 0.0007	DW	Stahl et al. 2009	79	0.0002
	Potato peel	0.007 – 0.02	DW	Stahl et al. 2009	79	0.004
	Peeled potato	<LOD – 0.002	WW	Lechner & Knapp 2011	NR	0.002
Fruit	**Tomato [b]**	**0.25**	**DW**	**Bao et al. 2020**	**94**	**0.015**
	Pea	0.03	DW	Blaine et al. 2014	82*	0.005
	Tomato	0.02 – 0.07	DW	Brignole et al. 2003	94	0.004
	Cucumber[b]	0.20	DW	Bao et al. 2020	96	0.008
	Cucumber	0.002	WW	Lechner & Knapp 2011	NR	0.002

Notes

DW = dry weight; WW = wet weight

NR = not required as plant concentrations on wet weight basis were available

LOD refers to the limit of detection

Bold cells indicate TFs used to derive HIL A. Note, these values will not match values in Table 2, as TFs in this table are for PFOS and TFs in Table 2 are based on PFOS + PFHxS.

[a] Moisture contents from Gebhardt and Thomas 2002, except potato and chicory data from USDA 2018 and values marked with * were from Blaine et al. (2014) where they measured the moisture content of their produce.

[b] Additional published literature and TFs since last review of PFOS TFs in OEH 2019.

PFHxS TFs

FSANZ (2017) conservatively advises that the toxicity of PFHxS should be considered equivalent to PFOS. Therefore, the human health soil criteria for PFOS applies to the sum of PFOS and PFHxS soil concentrations. A review of the PFHxS transfer factors from soil to plants was conducted for NEMP 2.0 and is presented in OEH 2019.

Briefly, the outcomes of the OEH 2019 review were the following:

- Identified studies with data on uptake of PFHxS into edible parts of plants (Blaine et al. 2013, Blaine et al. 2014 and Wen et al. 2014). Gobelius et al. 2017 was also identified however not included as it is on PFAS uptake into trees and not considered relevant for this assessment.
- Identified studies with data for non-edible parts of plants (Bräunig et al. 2018, Moshfeghi 2015 and Zhao et al. 2014).
- PFHxS TFs were consistently higher than TFs of PFOS.

There was insufficient data from published literature to derive reliable PFHxS TFs for all plant categories in the HILs calculator (NEPC 2013). For example, no data on PFHxS uptake into tuber vegetables was found. Therefore, available relevant data from the six studies listed above were compiled to calculate the ratio between the TFs for PFHxS and PFOS (see Table A2). The ratios between PFHxS and PFOS TFs ranged from 1.2 to 25 and the geometric mean of the maximum TFs for each plant species was used as an overall ratio to allow PFOS TFs to be converted to PFOS + PFHxS TFs. The geometric mean was 6.9 (OEH 2019). For the review in 2021 for NEMP 3.0, TFs for PFHxS were extracted from the papers assessed for PFOA and included in Table A2. These PFHxS TFs were found to fall within the range previously determined in OEH 2019 and the multiplier of 6.9 was retained for the combined PFOS + PFHxS TF derivation.

A combined PFOS + PFHxS TF for each plant category can be calculated using Equation A1, which assumes equal proportions of PFOS and PFHxS in the soil. In cases where either PFOS or PFHxS dominate concentrations, site-specific assessment could be used to provide a refined estimate of risk. This can be done by changing the proportions in Equation A1. Combined TFs for PFOS + PFHxS are listed in Table A3.

Equation A1

$$TF_{PFOS+PFHxS} = (TF_{PFOS} \times Proportion_{PFOS}) + (TF_{PFOS} \times Multiplier_{PFHxS} \times (1 - Proportion_{PFOS}))$$

where:

$TF_{PFOS+PFHxS}$ = combined TF for PFOS + PFHxS

TF_{PFOS} = soil to plant transfer factor for PFOS (Table A1)

$Multiplier_{PFHxS}$ = multiplier of 6.9 based on the geometric mean of ratios between PFHxS and PFOS TFs (as determined in OEH 2019)

$Proportion_{PFOS}$ = 0.5 assuming equal proportions of PFOS and PFHxS

Table A2 The ratio of PFHxS to PFOS TFs based on available PFHxS and PFOS soil to plant transfer factors for ASC NEPM plant categories.

Group	Plant	PFHxS TF	PFOS TF	TF in DW or WW	Ratio TFs	Study
		(mg/kg_{plant})/ (mg/kg_{soil})	**(mg/kg_{plant})/ (mg/kg_{soil})**			
Green Vegetable	Lettuce	1.1 – 7.6	0.1 – 1.7	DW	3.4 – 15	Blaine et al. 2013
	Celery	0.07, 2.3	0.05, 1.4	DW	1.4 – 1.7	Blaine et al. 2014
Root vegetable	Radish	0.85, 2.1	0.07, 0.7	DW	2.9, 13	Blaine et al. 2014
	Radish [a]	13	2.9	DW	4.5	Lasee et al. 2019
	Carrot [a]	1.1	1	DW	1.1	Lasee et al. 2019
Fruit	Pea	0.17	0.03	DW	6.7 [b]	Blaine et al. 2014
	Tomato [a]	0.28	0.25	DW	1.1	Bao et al. 2020
	Cucumber [a]	0.33	0.20	DW	1.7	Bao et al. 2020
Other	Alfalfa shoot [a]	12	1.4	DW	9	Lasee et al. 2019
	Alfalfa root [a]	11	4.3	DW	2.6	Lasee et al. 2019
	Radish shoot [a]	33	10	DW	3.3	Lasee et al. 2019
	Carrot shoot [a]	28	23	DW	1.2	Lasee et al. 2019
	Zucchini stems/leaves	0.20, 0.47	2.3, 4.2	DW	8.8, 12	Moshfeghi 2015
	Wheat grass	4.8	0.19	WW	25 [c]	Bräunig et al. 2018
	Wheat (grain)	0.1 – 0.2	0.06 – 0.08	DW	2.0 – 2.5	Wen et al. 2014
	Wheat (root/shoot)	0.4 – 0.7	0.1 – 0.5	DW	1.2 – 3.2	Zhao et al. 2014

Notes

TFs used to derive HIL A

[a] Additional published literature and TFs since last review of PFHxS TFs in OEH 2019.

[b] Result for one experiment only as all other soil treatments for PFHxS were < LOR.

[C] The TF for wheat grass grown at a firefighting training ground (TF = 78) was excluded, as the soil concentrations (13,400 μg/kg PFOS and 450 μg/kg PFHxS) were deemed not relevant to residential situations.

Table A3 PFOS+PFHxS transfer factors for HILs calculator assuming 50% PFOS and 50% PFHxS in soil (by mass) as per Equation A1 and a Multiplier$_{PFHxS}$ of 6.9.

Plant category	PFOS TF WW (from Table A1)	Sum of PFOS and PFHxS TF
Green vegetable	0.20 (Celery)	0.79
Root vegetable	0.15 (Radish)	0.58
Tuber vegetable	0.05 (Potato)	0.20
Tree fruit	0.015 (Tomato)	0.06

PFOA TFs

For PFOA, only few peer-reviewed studies were available with suitable TFs at the time of deriving the HIL A values in 2019. One of the future work outcomes from the NEMP 2.0 consultation was to review these, if appropriate newly published literature on PFOA uptake into plants becomes available.

Consistent with the OEH 2019 report, the review of TFs was focused on studies that provided data for uptake of PFOA from soil to plants, and plant types and compartments used for food consumption. Therefore, publications that used PFOA concentrations in irrigation water to calculate TFs were excluded from further consideration in deriving the HIL A, as these studies are not suitable to calculate soil to plant TFs.

A total of 9 additional publications (i.e. not already assessed by OEH 2019) with data on PFOA uptake from soil into plants were identified in 2021. Of these, 7 publications reported TFs from soil to edible plant compartments and these are presented in Table A4. Of the 7 publications, several were excluded from further consideration for the HIL A derivation:

- Navarro et al. (2013) was excluded as the paper was not published in a peer-reviewed journal and PFOA contamination was evident in some soil results. In addition, further critical quality control and quality assurance data was not reported.
- Eun et al. (2020) was excluded as the bioaccumulation factors were not readily available in the paper and data to calculate these was only presented graphically. Further, there was a disconnect between the time when vegetables were grown and soil PFAS concentrations were measured, which may have impacted resulting TFs.
- Lasee et al (2019) was a publication where the study design and QAQC were appropriate. Data for root vegetables were used from this paper (see Table 2), however, the data on Alfalfa sprouts was not used. This is because sprouts are not consumed in typical green vegetable amounts and are therefore not considered suitable representatives for the green vegetable category. High TF for PFAS in sprouts was also found as part of the TF review in OEH (2019) and were excluded at the time for the same reasons.
- Liu et al. (2019) was not used in the derivation of TFs as the study was conducted in close proximity to a large fluorochemical production facility in China (0.3 km to 10 km distance to the facility). The authors had discussed the potential for plant uptake of airborne PFAS, which may skew the results, especially for leafy vegetable parts grown above-ground. Detection of high levels of PFAS in rainwater from the area around the facility may confirm high loads of airborne PFAS (Liu et al. 2017) and recent literature have confirmed that plant

leaves may adsorb PFAS from the atmosphere (Chen et al. 2018, Tian et al. 2018). Nonetheless, the highest TFs from the paper for appropriate fruit and vegetable categories were used in a sensitivity analysis to determine if currently adopted PFOA TFs are protective (Details in Appendix B).

Only studies that had TFs higher than TFs for PFOA in OEH (2019) where considered further. Three papers were identified that contained higher TFs and were suitable for the derivation of updated TFs: Gredelj et al. (2020), Lasee et al. (2019) and Bao et al. (2020). All the assessed papers from OEH (2019) and these new papers are presented in Table A4.

When these TFs are used to derive the HIL A, the resulting HIL A value is 0.15 mg/kg. In the sensitivity analysis, the HIL A criterion results in a similar value of 0.09 mg/kg (see Appendix B). Both these values are close to the existing HIL A guidance for PFOA (0.1 mg/kg) reported in NEMP 1.0 and 2.0, which was based on limited data on PFOA transfer factors and incorporated a safety factor. As the calculations and sensitivity analysis based on the new data are within a similar range, the NCWG has retained the PFOA HIL A criterion of 0.1 mg/kg.

Table A4 PFOA soil to plant transfer factors (TF as mg/kg_{plant} / mg/kg_{soil}) for ASC NEPM plant categories, calculated from data in the listed data sources. DW = dry weight; WW = wet weight; NR = not required as plant concentrations on wet weight basis were available.

Group	Plant	PFOA TF	Calculation basis	Data source	% moisture content [a]	Max. TF adjusted to WW
		(mg/kg_{plant})/ (mg/kg_{soil})				
Green vegetable	**Chicory head [d]**	**1.5 – 1.7 [b]**	**DW**	**Gredelj et al. 2020**	**92**	**0.14**
	Chicory shoot [d]	**1.2 – 1.8**	**DW**	**Gredelj et al. 2020**	**92**	**0.14**
	Celery	0.1 – 0.7	DW	Blaine et al. 2014	86	0.10
	Lettuce	1.3, 2.5	DW	Blaine et al. 2013	96	0.10
	Lettuce	1.6 – 2.1	DW	Bizkarguenaga et al. 2016	96	0.08
	Lettuce	1.2	DW	Wen et al. 2016	96	0.05
	Lettuce [d]	0.71	DW	Felizeter et al. 2020	96	0.03
Root vegetable	**Radish [d]**	**18**	**DW**	**Lasee et al. 2019**	**95**	**0.93**
	Radish	3.0	DW	Wen et al. 2016	95	0.15
	Radish	0.5 – 0.9	DW	Blaine et al. 2014	90	0.09
	Carrot [d]	3.5 [c]	DW	Lasee et al. 2019	88	0.41
	Carrot peel	0.4 – 0.6	DW	Bizkarguenaga et al. 2016	88	0.07
	Carrot peel	0.04	WW	Lechner & Knapp 2011	NR	0.04
	Peeled carrot	0.3	DW	Bizkarguenaga et al. 2016	88	0.04

Group	Plant	PFOA TF	Calculation basis	Data source	% moisture content [a]	Max. TF adjusted to WW
	Peeled carrot	0.05	WW	Lechner & Knapp 2011	NR	0.05
Tuber vegetable	**Potato peel**	**0.02 – 0.03**	**WW**	**Lechner & Knapp 2011**	**NR**	**0.03**
	Peeled potato	0.01	WW	Lechner & Knapp 2011	NR	0.01
	Potato peel	0.002 – 0.008	DW	Stahl et al. 2009	79	0.002
	Peeled potato	0.0007 – 0.001	DW	Stahl et al. 2009	79	0.0002
Fruit	**Tomato [d]**	**0.65**	**DW**	**Bao et al. 2020**	**94**	**0.039**
	Cucumber [d]	0.93	DW	Bao et al. 2020	96	0.037
	Cucumber	0.03	WW	Lechner & Knapp 2011	NR	0.03
	Pea	0.03	DW	Blaine et al. 2014	82	0.005

Notes

Bold cells indicate appropriate TF for delivering a HIL A criterion

DW = dry weight; WW = wet weight

NR = not required as plant concentrations on wet weight basis were available

[a] Moisture contents from Gebhardt and Thomas 2002, except potato and chicory data from USDA 2018 and data from Blaine et al. (2014) where moisture content of produce was measured.

[b] TFs were recalculated from raw data for this report. A discrepancy in the studies' reported TFs was found: the reported maximum DW TF in the paper was 2.3.

[c] TFs were recalculated from raw data for this report. A discrepancy in the reported TFs was found: the reported maximum DW TF in the paper was 3.1.

[d] Additional published literature and TFs since last review of PFOA TFs in OEH 2019.

Appendix B: Sensitivity analysis for PFOS and PFOA

B.1 PFOS

While transfer factors for PFOS + PFHxS were not under review for NEMP 3.0, the papers chosen for updated PFOA TFs were cross-checked for PFOS. Two papers, Bao et al. 2020 and Lasee et al. 2020, had higher PFOS TFs compared with TFs reported in OEH (2019). To check how this will influence the HIL A value, NCWG calculated a combined PFOS + PFHxS TF (see Table B1) using the approach described in Appendix A.

Using these updated TFs in the ASC NEPM HIL A calculator resulted in no change to the HIL A criteria listed in NEMP 2.0 after rounding (HIL A of 0.01 mg/kg in NEMP 2.0 and 0.009 mg/kg based on the updated TFs). Therefore, the combined PFOS + PFHxS HIL A criteria was retained in NEMP 3.0.

Table B1 Comparison of PFOS + PFHxS transfer factors for deriving a HIL A criteria based on TFs from OEH (2019) and TFs based on Bao et al. 2020 and Lasee et al. 2020.

Vegetable category	PFOS TF (WW) and reference used in OEH 2019	PFOS + PFHxS combined TF from OEH, 2019 [a]	New PFOS TF (WW) and reference	New PFOS + PFHxS combined TF for due diligence checking [a]
Root vegetable	0.13, Radish (Wen et al 2016)	0.51	0.15, Radish (Lasee et al. 2019)	0.58
Fruit	0.005, Pea (Blaine et al 2014)	0.02	0.015, Tomato (Bao et al. 2020)	0.059

Notes

[a] Theratio of 6.9 was used to calculate a combined TF for PFOS + PFHxS as per OEH (2019)

WW = wet weight

B.1 PFOA

The paper published by Liu et al. (2019) was used for a sensitivity analysis, to determine if PFOA TFs used in the derivation of HIL A criteria are protective of a worst-case-setting, where maximum uptake may occur. Liu et al. (2019) investigated PFOA uptake into different vegetables and fruit in an open-air setting in close proximity to a large fluorochemical production facility. Plant exposure in such settings can stem from multiple exposure pathways, in this case uptake from exposure to soil, contaminated groundwater used for irrigation and plant exposure from atmospheric deposition of PFAS from the fluorochemical production facility. A further exposure pathway, not considered in detail in the study, but listed as a limitation, is the potential transformation of polyfluorinated PFAA-precursors. These additional exposure pathways may have led to increased PFOA (and other PFAS) concentrations in plants and could have skewed derived soil-to-plant TFs to higher values. The maximum PFOA uptake using TFs from the data presented in Liu et al. (2019), can be seen as a worst-case scenario, as chemical uptake may occur through three distinct uptake pathways, through soil, irrigation water and atmospheric deposition. It is reasonable to consider uptake from sites where the soil contamination arises

from application of contaminated water such as groundwater, surface water or rainwater. This is because for many contaminated sites in Australia, the soil contamination being investigated is secondary, arises from garden irrigation of contaminated surface or groundwater that migrates from distant primary source sites.

For each category of vegetables and fruit PFOA TF factors presented in Liu et al. (2019) were used in this sensitivity analysis, if they were higher than TFs reported in Table 2. This was the case for the green vegetables and fruit categories, where

- a maximum wet weight TF for lettuce of 0.47 was derived, which is higher than the TF for red chicory (0.14), and
- a maximum wet weight TF of 0.068 for peppers (capsicum) was derived, compared to the TF of 0.039 for tomato.

Using these maximum TFs for the fruit and green vegetable categories in this sensitivity analysis, the calculated HIL A is 0.09 for 10% fruit and vegetable consumption from homegrown produce and 0.02 for 50% fruit and vegetable consumption from homegrown produce. The current HIL A criteria in the NEMP 2.0 is 0.1 for 10% and 0.02 for 50% fruit and vegetable consumption from homegrown produce. These values are therefore within the same range (once rounded) and expected uncertainty compared with the HIL A currently reported in NEMP 2.0.