APPENDIX H – CRITERIA FOR PETROLEUM HYDROCARBONS, PFC AND DIOXINS

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Table of Contents

Text Tables

APPENDIX H

CRITERIA FOR PETROLEUM HYDROCARBONS, PFC AND DIOXINS.

1 INTRODUCTION

Criteria suitable for screening risks relevant to human health and ecological impacts are not currently available from Australian authorities for large number of chemical compounds. This includes many of the compounds included in the analytical suite as part of Cardno Lane Piper's (CLP) investigation at Fiskville Training College ('the Site'). This appendix provides a summary and justification of the criteria selected for certain compounds for which there is no local guidance. Compounds considered in this appendix are those potentially related to hot fire training activities; i.e. dioxins, petroleum hydrocarbons and perfluorinated compounds (PFC).

This appendix provides a summary of the following:

- Considerations in selecting human health screening criteria (Section 2).
- Considerations in selecting ecological screening criteria (Section 3).
- A summary of adopted criteria for dioxins, petroleum hydrocarbons and PFC is provided in Sections 4 to 6. Note that a limited review of available ecological criteria for PFC available from overseas agencies is also provided.

Criteria adopted for water (Table 1-1) and soil (Table 1-2) that are relevant to commercial/industrial land use and fine grained soil are provided below. For other land uses (agriculture) and soil types (coarse grained soil), the relevant sections for the specific compounds should be consulted in order to select appropriate criteria. Exceedance of these criteria does not necessarily indicate a potential risk, but should be a trigger for more detailed investigation.

Table 1-1: Adopted Criteria for Water (µg/L).

Compound	EIL Water	Source (EIL)	Human Health Drinking Water	Source (Human Health)
Dioxins	No value	-	7.9×10^{-6} or 7.9 pg/L	Derived in house
Benzene	300	NEPC (1999)	1	NHMRC (2011)
Toluene	300	NEPC (1999)	800	NHMRC (2011)
Xylene	No value	NEPC (1999)	600	NHMRC (2011)
Ethyl Benzene	90	CCME (1999c)	300	NHMRC (2011)
F1 (C_6 to C_{10})	No value	-	15,000	WHO (2008)
F2 ($C_{>10}$ to C_{16})	No value	-	90	WHO (2008)
F3 ($C_{>16}$ to C_{34})	No value	-	90	WHO (2008)
F4 ($C>_{34}$ to C_{40})	No value	-	No value	-
PFOS	5.1	Geisy (2009)	0.2	US EPA (2009a)
PFOA	1,700	MPCA (2007a)	0.4	US EPA (2009a)
6:2 FTS	5.1	Adopted PFOS	0.2	Adopted PFOS

Table 1-2: Adopted Criteria for Soils (mg/kg).

Compound	EIL Soil (Sediment)	Human Health Direct Contact	Sources
Dioxins	0.85×10^{-6} or 0.85ng/kg	4×10^{-6} or 4ng/kg	CCME (2001 & 2002)
Benzene	310	11	CCME (2004a)
Toluene	330	82,000	CCME (2004b)
Xylene	230	560,000	CCME (2004c)
Ethyl Benzene	430	36,000	CCME (2004d)
F1 (C_6 to C_{10})	217	-	Warne (10010)
	-	19,000	CCME 2008
F2 ($C_{>10}$ to C_{16})	172	-	Warne (2010)
	-	10,000	CCME 2008
F3 ($C_{>16}$ to C_{34})	2500	-	CCME 2008
	-	28,000	NEPC (1999)
F4 ($C>_{34}$ to C_{40})	6600	-	CCME 2008
	-	Res	NEPC (1999)
PFOS	0.37 (0.067)	-	EA 2004
	-	6	US EPA (2009b)
PFOA	-	16	US EPA (2009b)
6:2 FTS	0.37 (0.067)	6	Adopted from PFOS values
EILs for sediments are provided in brackets for PFOS and 6:2FTS.			

2 ASSUMPTIONS - HUMAN HEALTH SCREENING CRITERIA

The screening criteria adopted for dioxins, petroleum hydrocarbons and PFC in investigations at the Site are based on the following assumptions:

- *Land Use*: Criteria for human health are based on land use at the Site being commercial/industrial. Where agricultural use is relevant, the section for the relevant compound (below) should be consulted in order to select appropriate criteria.
- *Soil Type*: The predominant soil type on-site is silty clay. However, there are areas on-site which include coarse-grained soils (e.g. around Dams 1 and 2). Criteria for fine-grained soils are provided in the summary in Section 1. Where coarse-grained soils are identified, the section for the relevant compound (below) should be consulted in order to select appropriate criteria.

The following provides a summary of the approach adopted for screening criteria in the assessment of human health impacts:

- *Water*: Drinking water guidelines are generally adopted as conservative criteria for an initial screen of human health impacts from surface waters.
- *Soils*: The criteria considered are based on direct contact with soil[1]. Criteria relevant to soil vapour are not considered here for volatile fractions of petroleum hydrocarbons (F1 and F2). For the soil-vapour criteria please refer to CRC (2011).
- *Sediments*: In general, soil quality guidelines are adopted as criteria for sediment where no suitable criteria are available.

[1] Direct contact with soil refers to ingestion of soils and/or dermal contact with soils

3 CONSIDERATIONS FOR SELECTING ECOLOGICAL SCREENING CRITERIA

The selection of suitable ecological screening criteria is dependent on a number of factors including consideration of the management goal (e.g. protection of aquatic ecosystems), the type of water body and the ecotoxicological information considered in their derivation and an appropriate level of protection to be afforded. In order to ensure appropriate consideration was given to selecting an appropriate criterion from overseas agencies this review was conducted in accordance with the following steps as outlined in ANZECC (2000):

- *Define the Management Aims*: This requires knowledge of an ecosystem, potential impacts to the ecosystem and an understanding of the approach used to select (and/or derive) appropriate criteria for use in Australia based on Australian and New Zealand Water Quality Guidelines (ANZECC 2000). Criteria are used in Australia based on an appropriate level of protection afforded an aquatic ecosystem, i.e. selecting a percentage of species in an ecosystem that require protection. The steps used in the process are as follows:
  1. Describe the water body to be protected.
  2. Determine Environmental values to be protected.
  3. Determine the level of protection.
  4. Identify environmental concerns.
  5. Determine major natural and anthropogenic factors affecting the ecosystem:
  6. Determine management goals:
- *Determine appropriate screening criteria or trigger values*: A review of available criteria is provided.

The six steps required for defining the management aims of downstream waterways are discussed below.

3.1 Describe the water body to be protected

The surface water bodies considered are Lake Fiskville (located on the Site) and waterways downstream of the Site, which have previously been described (Cardno 2014). A summary of these water bodies and the degree of modification is outlined below:

- *Lake Fiskville:* The Lake is a man-made feature created by damming the Beremboke Creek, before CFA occupied the Site. It is occasionally used by CFA as an emergency water source (perhaps once annually in drought. The lake is a highly modified ecosystem which now supports extensive growth of macrophytes (including emergent rushes and submerged/floating plants) and numerous water birds including black swans, cormorants, moorhens and black ducks. The lake also supports a population of introduced fish (redfin, mosquitofish) as well as eels and yabbies.
- *The Beremboke Creek*: A small, shallow, stream which leaves the Site at its southern boundary and runs through pasture on adjacent land. Dams are also located along or adjacent to the creek downstream of the Site. These dams are believed to be used for stock water. Limited flora is evident in this section of the creek. The creek is considered a highly modified and ephemeral water body.
- *The former marsh swamp area*: The swamp (which starts approximately 6km downstream of the Site and extends to 9.5km from the Site) has been drained for agricultural use and

currently includes at least one drainage channel. The swamp is also considered a highly modified ecosystem.

- *The Eclipse Creek*: This creek is the continuation of Beremboke Creek, downstream of the swamp. The creek runs through pasture and is also considered highly modified and ephemeral. A shallow water hole near the site of inspection was observed to be choked with emergent rushes.
- *The Moorabool River*: Eclipse Creek flows into the Moorabool River approximately 20 km downstream of Lake Fiskville. The river has extensive riparian habitat with minimal disturbance which supports native flora and fauna including various fish species. However, there are various barriers that prevent fish movement. Environmental releases from Lal Lal Reservoir were made to improve salinity, conductivity, and reduce impact on fish by allowing improved movement between ponds (CCMA 2009). Releases were considered necessary as an assessment of in-stream river health rated the river as being in poor to very poor condition due to competing demands which "*has led to severe alteration of the river's natural flow regime*". Competing demands include; impact from farm dams, extraction of groundwater and possibly climate change (CCMA 2009). The Moorabool River is considered moderately modified.

Note that the Beremboke Creek, the Swamp drainage channel and the Eclipse Creek are ephemeral in nature. The Moorabool River is considered ephemeral in in some years with extreme seasonal fluctuations.

3.2 Identify Environmental values to be protected

Relevant ecological receptors to be considered include biota supporting ecological processes (e.g. microorganisms), wildlife (e.g. piscatorial birds) and flora (native and introduced).

Lake Fiskville and the Moorabool River both support fauna and flora. Hence, ecological considerations include potentially undesirable impacts to aquatic life and secondary exposures[2] to wildlife (birds, mammals). The ephemeral nature of the Beremboke Creek, a drainage channel and Eclipse Creek suggests there is limited opportunity for ecological receptors to be present in this ecosystem.

3.3 Determine the level of protection

The ANZECC (2000) guidelines outline three different levels of protection depending on the state of the ecosystem. The levels of protection for the different surface water bodies are as follows:

- *Pristine and/or high conservation value ecosystems*: These ecosystems are afforded **99%** protection in Australian aquatic ecosystems. Surface water bodies downstream of the Site do not fit this description.
- *Slightly to moderately disturbed ecosystems*: The level of protection afforded these ecosystems is **95%**. The Moorabool River is considered to be moderately modified. Should water flows in the River increase above levels in 2008 and the impacts from farming reduce, then the river may return to a slightly modified state. Other barriers preventing this River from being considered pristine include barriers that prevent fish movement.
- *Highly disturbed ecosystems*: The default level of protection for these ecosystems is **90% or 80%** depending on state jurisdiction. Choosing a higher level of protection (e.g. 95%) might be applied in circumstances when an aim is to improve quality of water in the system

[2] Secondary exposures refer to exposure pathways where the receiving organism is not directly exposed to a contaminant in water or soil, e.g. animals higher in the food chain which eat smaller animals.

(ANZECC 2000). Lake Fiskville, the Beremboke Creek, the drainage channel and the Eclipse Creek are considered to be highly modified surface water bodies. Flora and Fauna are abundant around Lake Fiskville, limited in the creeks and assumed to be limited in the drainage channel.

Note that the level of protection refers to the percentage of species that should be protected by a selected screening criterion. As an example, a protection level of 95% is meant to protect 95% of all aquatic species in a surface water body. For highly disturbed ecosystems a higher level of protection is ideal where the long-term aim is to improve water quality, particularly where a management goal is that there is no change in biodiversity in the impacted ecosystem. For highly disturbed ecosystems this means that "*the same guidelines as for slight-moderate disturbed systems*" might be applied (ANZECC 2000).

3.4 Identify environmental concerns

PFCs and petroleum hydrocarbons have been identified in Lake Fiskville and creeks downstream of the site as a result of on-site activities, i.e. hot-fire training. Petroleum hydrocarbons have widespread use. The use of PFCs is becoming increasingly widespread, as is the presence of PFCs in the in the environment. PFCs are used in various consumer products including carpets, pots, pans, paper, etc.). Dioxins are also considered here as they may be present as a result of the combustion that occurs during hot-fire training.

PFCs are fluorosurfactants that have been identified as compounds of environmental concern as they have been detected in water and sediment of various water bodies including Lake Fiskville and in the downstream. Some PFCs have also been identified in samples from fish, crustaceans, and aquatic plants. The PFCs of most interest are Perfluorooctane Sulfonic Acid (PFOS), Perfluorooctane Carboxylic Acid (PFOA) and 6:2 Fluorotelomer Sulphonic Acid (6:2 FTS). There is the potential for PFC to bioaccumulate in the environment. Therefore, in some cases it may be considered necessary to increase the level of protection (e.g. 98% instead of 95% and 85% instead of 80%).

3.5 Major natural and anthropogenic factors affecting the ecosystem

PFCs and petroleum hydrocarbons have been identified in Lake Fiskville and creeks downstream of the Site associated with on-site activities, i.e. hot-fire training. Dioxins are also considered as a result of combustion that occurs during training. PFCs in particular are becoming more widespread in the environment as a result of their use in various consumer products (carpets, pots, pan, paper, etc.).

3.6 Determine management goals

The primary management goal is the protection of aquatic ecosystems downstream of the Site. Consideration is also given to the protection of wildlife dependent on these ecosystems such as water birds (secondary exposures) and primary industries (mammals, stock drinking water). Therefore, consideration is given to identify criteria that protect the following:

- Aquatic Ecosystems (including water and sediment)
- Mammalian Species and Birds
- Biota and organisms (in the soil compartment)

3.7 Determine Appropriate Screening Criteria or Trigger Values

Criteria for dioxins and petroleum hydrocarbons are mainly adopted from Australian guidance (limited) or Canada, specifically from Canadian Council of Ministers of the Environment (CCME). Limited guidance is available for criteria for PFC. Therefore, screening criteria for PFC are adopted with consideration given to:

- How these sorts of criteria are derived in Australia (Section 3.8)
- The criteria adopted for protection of management goals (Section 6)
- The relevant criteria identified in available literature (Section 6).

3.8 Summary of How Ecological Criteria are Derived in Australia

This section provides a short summary of how criteria should be applied/derived in Australia. ANZECC (2000) should be consulted for a detailed description. Three grades of criteria are outlined by ANZECC (2000) that are defined by the amount of ecotoxicological data available and hence the level of confidence that can be afforded them. They are classified as either high, moderate or low reliability criteria and are broadly summarised as follows:

- *High reliability criteria*: A statistical distribution approach is used based on chronic data from multiple species.
- *Moderate reliability criteria*: Similar to approach for the high reliability criteria above except that acute toxicity data is used in statistical distribution and then converted to a chronic value.
- *Low reliability criteria*: An assessment factor (AF) approach is utilised. These criteria are screening in nature and should be as interim values, due to uncertainties in their derivation. According to ANZECC (2000), "*there is no reliable way to predict what changes in ecosystem protection are provided by an arbitrary reduction in the factor*".

The majority of ecological criteria identified in the following sections have been derived using one of the approaches outlined above.

4 DIOXINS

Criteria for dioxins are typically derived for soils and sediments but not for water. Dioxins (and furans) have very low water solubility. Therefore, they are most likely to partition to soils and sediments. For this reason, neither the WHO (2010) nor the CCME (2002) have derived water quality guidelines for these substances and analysis of water was not included as part of the National Dioxin Program (DEH 2005). This indicates that soils and sediments are of primary concern for human health and ecological impacts. A summary of criteria available for dioxins is provided in Table 4-1, including a human health-based criterion for water derived in-house by CLP.

Table 4-1: Adopted Criteria for Dioxins.

Criteria	Water (pg/L)	Source	Soil (ng/kg)	Source
Human Health	7.9	Derived in-house [a]	4[b]	CCME (2002)
Ecological	nv	-	0.85[c]	CCME (2001)

nr = not relevant, nv = no suitable value identified in literature.

a. Based on a Tolerable Monthly Intake from NHMRC (2002) for Dioxins & Furans (70pg/kg.bw/month), a 70kg person drinking 2L water per day and only 10% is permitted to come from this pathway. (i.e. 70pg/kg.bw/month ÷ 31 days x 0.1 x 70kg.bw ÷ 2L/day = 7.9pg/L)

b. The adopted screening value for dioxins is set for various land uses with the most sensitive population identified as a toddler. A provisional screening value of 175ng/kg for an adult, also derived by CCME 2002), should be given consideration for commercial/industrial sites where access to soils, by the general public (especially children) is restricted

c. A probable effect level of 21.5ng/kg was also noted in CCME (2001).

Detection levels for dioxins are likely to result in a toxic equivalency (TEQ) value that is greater than this provisional screening criterion. Therefore, consideration will be required of dioxin results to the conservatisms in the derivation of this criterion:

- That only 10% of dioxins are permitted via this pathway (ingestion). Dioxins from other sources are assumed to be low therefore the amount of dioxins permitted from this pathway could be higher, e.g. 50% which would result in a criterion of 39.5 pg/L.
- The assumption that dioxins are present at half the limit of reporting should be tested. An assessment of the dioxins that have contributed to the TEQ calculation should be made, i.e. are they all at non-detect levels.
- Whether the water being assessed is used for drinking water at the relevant location.

5 PETROLEUM HYDROCARBONS

Petroleum hydrocarbons include benzene, toluene, xylene, ethylbenzene and four Total Petroleum Hydrocarbons (TPH) fractions (F1, F2, F3 and F4). There are criteria available for some of these compounds in Australia (e.g. ecological criteria for benzene in NEPC (1999). These are supplemented by criteria available from the CCME and the World Health Organisation (WHO). Where criteria are available from both sources, the NEPC (1999) takes precedence.

5.1 Human Health criteria for petroleum hydrocarbons

Human health screening criteria for petroleum hydrocarbons in water are based on drinking water guidelines. Soil criteria are also available for these hydrocarbons and have been derived for specific land uses. A summary of these criteria is provided in Table 5-1 and 5-2 below.

Table 5-1: Human Health criteria for petroleum hydrocarbons in water (µg/L).

Compound	Aromatics	Aliphatic	Source
Benzene (10^{-6} risk)	**1** (10)	nr	NHMRC (2011) (WHO 2008 criteria in brackets)
Toluene[a]	**800** (700)	nr	
Xylene[a]	**600** (500)	nr	
Ethyl Benzene[a]	**300** (300)	nr	
F1 (C_6 to C_{10})	See BTEX	**15,000**	WHO (2008)
F2 ($C_{>10}$ to C_{16})	**90**	300	
F3 ($C_{>16}$ to C_{34})	**90**	nv	
F4 ($C_{>34}$ to C_{40})	**nv**	nv	

Bolded criteria are adopted for investigations at the Site as land used is considered commercial/industrial targeted areas.
nr = not relevant, nv = no suitable value identified in literature.
a. Aesthetic criteria (not considered here) are lower than health based criteria provided for these compounds

Table 5-2: Human Health Criteria for Petroleum Hydrocarbons in Soil (mg/kg).

Compound	Commercial	Agriculture	Source
Benzene (10^{-6} risk)	**11**	11	CCME (2004a)
Toluene	**82,000**	22,000	CCME (2004b)
Xylene	**560,000**	150,000	CCME (2004c)
Ethyl Benzene	**36,000**	10,000	CCME (2004d)
F1 (C_6 to C_{10})	**19,000**	12,000	CCME (2008)
F2 ($C_{>10}$ to C_{16})	**10,000**	6,800	
F3 ($C_{>16}$ to C_{34})	450[a] or **28,000**[b] (23000)	nv (15,000)	NEPC (1999) (CCME 2008 criteria in brackets)
F4 ($C_{>34}$ to C_{40})	**280,000**[b] (Res)	nv (21,000)	

Bolded criteria are adopted for investigations at the Site as land used is considered commercial/industrial targeted areas.
a. Health investigation level for aromatic fraction
b. Health investigation level for aliphatic fraction

5.2 Review of Ecological Criteria for Petroleum Hydrocarbons

Limited ecological criteria are available for petroleum hydrocarbons in water. Criteria for xylene, and the petroleum hydrocarbon fraction F1 to F4 are not available. Ecological criteria for water are shown in Table 5-3 below. Ecological criteria for soils, shown in Table 5-4, are based on criteria derived by the CCME. A review of these ecological guidelines, reported in Warne (2010), concluded that the protocols used in their derivation were suitable for Australia. It is noted, however, that for 2 fractions (F1 and F2) lower criteria were calculated by Warne (2010). Therefore the values from Warne (2010) take precedent over the criteria from CCME.

Table 5-3: Summary of ecological criteria for petroleum hydrocarbons in water (µg/L).

Compound	Aquatic Ecosystems - Fresh water	*Source*
Benzene	**300** (370)	NEPC (1999) (CCME 1999a, b, in brackets)
Toluene	**300** (2)	
Xylene	nv	-
Ethyl Benzene	**90**	CCME (1999c)
F1 (C_6 to C_{10})	nv	-
F2 ($C_{>10}$ to C_{16})	nv	
F3 ($C_{>16}$ to C_{34})	nv	
F4 ($C_{>34}$ to C_{40})	nv	
Bolded criteria are adopted for investigations at the Site as land used is considered commercial/industrial in targeted areas and soils are predominantly silty clay, i.e. a fine grain soil. nv = no suitable value identified in literature.		

Table 5-4: Summary of ecological criteria for petroleum hydrocarbons in soil (mg/kg).

Compound	Commercial	*Agriculture*	*Source*
Fine-grained soils			
Benzene	**310**	25	CCME (2004a)
Toluene	**330**	110	CCME (2004b)
Xylene	**230**	65	CCME (2004c)
Ethyl Benzene	**430**	120	CCME (2004d)
F1 (C_6 to C_{10})	320 (**217**)	210	CCME (2008) (Warne (2010) criteria in brackets)
F2 ($C_{>10}$ to C_{16})	260 (**172**)	150	
F3 ($C_{>16}$ to C_{34})	**2,500**	1,300	
F4 ($C>_{34}$ to C_{40})	**6,600**	5,600	
Coarse-grained soils			
Benzene	180	25	CCME (2004a)
Toluene	250	75	CCME (2004b)
Xylene	350	95	CCME (2004c)
Ethyl Benzene	300	55	CCME (2004d)
F1 (C_6 to C_{10})	320	210	CCME (2008)
F2 ($C_{>10}$ to C_{16})	260	150	
F3 ($C_{>16}$ to C_{34})	1,700	300	
F4 ($C>_{34}$ to C_{40})	3,300	2,800	
Bolded criteria are adopted for investigations at the Site as land used is considered commercial/industrial in targeted areas and soils are predominantly silty clay, i.e. a fine grain soil.			

6 PERFLUORINATED COMPOUNDS

6.1 Human Health Criteria for Perfluorinated Compounds

A summary of criteria suitable for screening the PFCs relevant to the current investigation is provided below in Table 6-1. Drinking water criteria from USEPA (2009) are primarily used for screening human health impacts. In the absence of a specific value for 6:2 FTS, the value for PFOS is substituted as a conservative approach for screening risks associated with 6:2 FTS. Included in the table below are criteria derived by RIVM (2010) for secondary exposure pathways (e.g. consumption of fish). Before applying the secondary exposure criteria, a range of factors need to be considered and readers are referred to RIVM (2010) for specific guidance.

Table 6-1: Summary of human health criteria for PFC

Compound	Criteria Name	Criterion Value	Source	Media
Drinking Water				
PFOS, 6:2 FTS	PHA	0.2 µg/L	USEPA (2009a)	Water
PFOA	PHA	0.4 µg/L		
PFOS	$MPC_{DW,Water}$	0.53 µg/L	RIVM (2010)	
PFOS and PFOA	GV	0.3 µg/L	DWC (2006), DWI (2009)	
Recreational Guidelines (Water)				
A factor of 10x can be applied to drinking water guidelines for primary contact recreation as dermal exposure to PFC is considered an incomplete/insignificant exposure pathway compared to the oral pathway (NHMRC 2008). This is because PFCs in general have low rates of dermal absorption. (e.g. PFOS criterion = 0.2 x 10 = 2 µg/L)				Water
Direct Contact With Soil				
PFOS,	SSL	6 mg/kg	USEPA (2009b)	Soil
PFOA	SSL	16 mg/kg		
6:FtS		6 mg/kg	Assumes same as PFOS[a]	Soil
Secondary Exposure Pathways				
PFOS	$MPC_{Eco,\ hh,food}$	0.00065 µg/L	RIVM (2010)	Water
PFOS	$MPC_{HH,food}$	9.1 ng/g		Food (Fish)

PHA = Provisional Health Advisory, GV = guideline value, SSL = Soil Screening Level, $MPC_{DW,Water}$ = Maximum Permissible Concentration in drinking water, $MPC_{Eco,\ hhfood}$ = Minimum Permissible Concentration in water with fish to be consumed by humans, $MPC_{Eco,\ hhfood}$ = Minimum Permissible Concentration in food (fish) to be consumed by humans
a. Note no criteria was identified for 6:2FtS, as result Cardno Lane Piper adopted PFOS criteria value as a screening level only.

Criteria for the secondary exposure pathway criteria as provided in Table 7-1 are provisional guideline values that are based on PFOS levels in edible fish (9.1 ng/g, $MPC_{HH,food}$) or PFOS levels in water that edible fish live in. These criteria are not considered "*a product safety standard*" (RIVM 2010). As an example, the $MPC_{HH,food}$ was calculated using a tolerable daily intake (TDI) of 0.15µg/kg/day and based on assumptions that:

- The daily human consumption fish products per day is 115g

- Only 10% of the tolerable daily intake is attributed to this exposure route.

The $MPC_{HH, food}$ can be adjusted to a value of 348ng/g[3] by:

- Substituting a fish consumption consistent with what is typical in Australia, i.e. less than 30g of fish products per day (enHealth 2012).
- Attributing 100% to this route of exposure as the contribution of PFC from background sources is assumed to be very low.

6.2 Review of ecological criteria for perfluorinated compounds

Relevant screening criteria selected from a review of available literature on PFC are provided in Table 6-2 below. A short summary of the key studies used by various agencies to derive criteria is provided in the following section. A criterion for Alcohol Ethoxylates (AE) has also been included as it is likely that fluorosurfactants will be replaced by hydrocarbon surfactants in fire-fighting foam products. A review of criteria for hydrocarbon surfactants has not been performed.

Table 6-2: Summary of ecological criteria adopted for PFCs

CoPC	Criteria Name	Criterion Value	Source	Media
Aquatic Ecosystems				
AE	FTV	140 µg/L	ANZECC (2000)	Water
PFOS (6:2FTS)	CCC	5.1 µg/L	Giesy (2010)	
PFOA	CC	1,700 µg/L	MPCA (2007a)	
PFBS	CCC	1,938,000 µg/L	Giesy (2010)	
Biota and Organisms (Soil and Sediment Compartments)				
PFOS	$PNEC_{Soil}$	373 µg/kg	EA (2004)	Soil
PFOS	SQG	67 µg/kg	EA (2004)	Sediment
Mammalian Wildlife				
PFOS	MPC_{Oral}	37 µg/kg	RIVM (2010)	Diet (food)
PFOS	$MPC_{Eco,sp}$	0.0026 µg/L	RIVM (2010)	Water
PFOS	ENEV	408 ng/g	EC (2006)	Liver
Birds				
PFOS	MPC_{Oral}	330 µg/kg	RIVM (2010)	Diet (food)
PFOS	CCC	0.047 µg/L	Giesy (2010)	Water
Notes: FTV = Freshwater Trigger Value, $PNEC_{Soil}$ = Practical No Effect Concentration in soil, CCC = Criteria Continuous Concentration, CC = Chronic Criteria, MPC_{Oral} = Maximum Permissible Concentration Oral Pathway, ENEV = Estimated No Effect Value, SQC = Sediment Quality Guideline.				

6.2.1 Criteria for Aquatic Ecosystems

Criteria are available for AE (ANZECC 2000); they are 50 µg/L, 140 µg/L and 360 µg/L for 99%, 95% and 80% levels of protection respectively. These criteria are only suitable for AE and do not apply to other types of hydrocarbon surfactants or fluorosurfactants. Criteria for other hydrocarbon surfactants are not discussed further.

Ecological criteria have been derived by various agencies overseas[4] for a limited number of PFC including PFOS, PFOA and Perfluorobutane Sulfonic Acid (PFBS). The criteria derived

[3] Provisional guideline value = 9.1 x 115 ÷ 30 x 100%÷10% = 348ng/g

span multiple orders of magnitude as shown in Table 6-3 below. This range is as a result of the methodology used by regulatory agencies to derive their criteria, the departure point selected (e.g. LC_{50}, NOEC etc.) and/or the assessment factor (AF) that was applied.
Ecological criteria shown in Table 6-3 were derived using either:

- *Acute and Chronic Toxicity Studies*: A departure point is selected based on an acute effect (e.g. LC_{50} data), i.e. a Final Acute Value (FAV). An acute to chronic ratio (ACR) is then derived by making a comparison of effects from acute and chronic studies in the same species. If studies are insufficient to derive an ACR then a default value of 18 may be applied. The final chronic criteria is derived by multiplying the FAV by the ACR, i.e. Chronic Criteria = FAV × ACR. Note that the criteria derived by Giesy (2010) used statistical methods to determine a FAV and is considered a moderate reliability criterion; or
- *Chronic Toxicity Studies Only*: A departure point is selected based on effects that impact a global population (e.g. 10d-NOEC for growth and survivability). An assessment factor is applied which is dependent on the number of studies available. These are considered low-reliability criteria and are suitable as screening criteria.

[4] Regulatory agencies include United States Environment Protection Agency (USEPA), Dutch Environment Agency (RIVM) and Environment Canada (EC).

Table 6-3: Summary of PFC criteria derived for the protection of aquatic ecosystems (µg/L)

Criteria Name	Species	Critical Effect	Departure Point	Assessment Factor	Value	Source
PFOS						
PNEC	*Pimephales promelas* (Fathead minnow)	Growth (42-d NOEC)	300 (250)	10	30	EA (2004)
CC	*Chironomus tentans* (Midge)	FAV based on L(E) C_{50} (GMAV)	170	9.1 (ACR)	19	MPCA (2007a)
CCC	Various species	FAV[a] based on L(E)C_{50} (GMAV)	42	8.3 (ACR)	5.1	Giesy (2010)
ENEV	*Chironomus tentans* (Midge)	Growth and Survival (10-d NOEC)	49.1	100	0.49	EC (2006)
MPC_{Eco}	*Chironomus tentans* (Midge)	Total Emergence (36d- LOEC)	2.3	100	0.023	RIVM (2010)
PFOA						
CCC	*Daphnia magna* (Water flea)	48-hour EC_{50}	297,000	6.1 (Dataset) 17 (ACR)	2,900	Giesy (2010)
CC	*Daphnia magna* (Water flea)	FAV based on L(E) C_{50} (GMAV)	31,000	18[b] (ACR)	1,700	MPCA (2007b)
PNEC	*Gobiocypris rarus* (Rare minnows)	Hormonal changes (28-d NOEC)	3,000	100	30	EC (2010)
PFBS						
CCC	*Pimephales promelas* (Fathead minnow)	96-hr LC_{50}	1,938,000	8 (Dataset) 10 (ACR)	24,000	Giesy (2010)

Notes: PNEC = Practical No Effect Concentration, CCC = Criteria Continuous Concentration, CC = Chronic Criterion, MPC_{Eco} = Maximum Permissible Concentration Ecological, ACR = Acute to Chronic Ratio, ENEV = Estimated No Effect Value, FAV = Final Acute Value, SAV = Secondary Acute Value.
a. FAV and SAV modelled using 5th percentile from four lowest acute values to give a 95th percentile value.
b. Default value as no chronic data identified

The criteria shown in Table 6-3 are predominantly screening criteria that have been derived to protect the most sensitive species identified. As discussed earlier (Section 3.3), the relevant criterion for the protection of waterways in Victoria is dependent on the level of protection afforded a waterway, the location of the waterway and the amount of modification that has occurred to the waterway.

Giesy (2010) derived chemical concentrations intended to ensure the protection of 95% of aquatic species. These (known as the Criteria Continuous Concentration, or CCC) are derived to "*provide reasonable protection to ecologically and commercially important species under most circumstances such that overprotection or under-protection of aquatic species is avoided*". The CCC of 5.1 µg/L for PFOS was derived using a FAV of 42 µg/L (Giesy 2010) and by using an ACR of 8.3 determined from studies in 3 different species. The FAV was derived using statistical analysis (5th percentile) considering acute toxicity data from multiple studies and species and selecting the four lowest values for statistical analysis. This included data from a study (MacDonald 2004) which identified the most sensitive species (*Chironomus tentans*). It was noted by Giesy (2010) that *C tentans* is approximately 40 times more sensitive to PFOS compared to the next most sensitive species.

The CCC derived is considered to be skewed low due to the reliance of the statistical method on the four lowest toxicity values rather than the whole dataset available. It is noted that the LOEC of 2.3 µg/L determined by MacDonald (2004) and used by RIVM (2010) to derive the MPC_{Eco} was not selected as a departure point by Giesy (2010) for use in the statistical analysis. This is not specifically addressed by the author however EC (2006) have commented on the lack of confidence in longer exposures from the study by MacDonald (2004), i.e. "*there is high confidence in the 10-day exposure values while the 60-day exposures should be treated with caution*". It is noted that the 10-day NOEC was selected by EC (2006) for derivation of their Estimated No Effect Value (ENEV) instead of the 36-day LOEC. The CCC derived by Giesy (2010) for PFOS is suitable for use as a screening criterion that offers a suitable level of protection for slightly to highly modified ecosystems, i.e. the waterways downstream of the Site. Giesy (2010) notes that "*chronic water concentrations less than or equal to 0.46 mg PFOS/L should not pose a significant adverse risk to aquatic organisms*". Consideration should be given to this where the CCC is exceeded and further assessment is being considered.

A criterion derived by Giesy (2010) for PFOA (CCC = 2,900 µg/L) is three orders of magnitude higher than derived for PFOS (CCC = 5.1 µg/L). The CCC for PFOA is considered a low reliability criterion due to a lack of data. The CCC for PFOA included consideration of data from a study by MacDonald (2004) discussed above for PFOS including the most sensitive species, *C tentans*. This species was not as sensitive to PFOA as it was for PFOS. This suggests that the functional group impacts on the sensitivity of *C tentans* to PFC. An assessment factor (AF) of 6.1 was applied to the lowest acute value (EC_{50} of 297,000 µg/L in Daphnia magna).

A much lower criterion for PFOA (PNEC = 30 µg/L) was derived by the EC (2012) from a chronic study in the Rare Minnow. It is not clear whether the effects noted (e.g. liver hypertrophy) are indicative of a toxicological endpoint for population dynamics and may not be predictive of population level effects. A requirement for deriving a PNEC is that population effects are noted. The PNEC is adopted here as a screening criterion for PFOA as conservative measure.

No criteria are available for 6:2 FTS. The only publically available ecotoxicological information identified for 6:2FTS is from the supplier (Du Pont 2012), which is summarised below in Table 6-4. This data was compared with information for PFOS, which included a 90-d fish

NOEC of 290 µg/L. The data suggests that 6:2FTS is less than PFOS toxic to aquatic species, however the data source is considered of low reliability as no information on how these ecotoxicological values were determined was provided. A criteria similar to a PNEC of 2.9 µg/L could be calculated using an AF approach (AF = 100). This is lower than the criterion adopted for PFOS to protect 95% of species in a water body. The criterion selected for PFOS of 5.1 µg/L is adopted in this case for 6:2FTS to protect 95% of species. There is low confidence in adopting this value based on the information provided.

Table 6-4: Summary of ecotoxicological data for 6:2FTS

Property	6:2 FTS	PFOS
Acidity	2 to 3	<1
Fish LD_{50}	>107 mg/L	78 mg/L
Invertebrate LC_{50}	> 109 mg/L	58 mg/L
Algae EC_{50}	> 96 mg/L	48 mg/L
Fish 90-day NOEC	2.62 mg/L	0.29 mg/L
Bioaccumulative	No	Yes

A single criterion of 24,000 µg/L was derived for one other PFC with a sulfonic acid functional group, i.e. PFBS. This is also a low reliability criterion derived by Giesy (2010) in a similar manner to PFOA due to a lack of data. An AF of 8 (database deficiencies) and 10 (ACR) were applied to the lowest acute value (LC_{50} of 1,938,000 µg/L in Fathead Minnow). PFBS appears to have much lower toxicity than PFOS spanning multiple orders of magnitude.

Bioaccumulation and toxicity of PFC appears to increase with chain length for compounds with both sulfonic acid and carboxylic acid functional groups. Further review is required for selecting screening criteria for PFC other than those considered here (PFOS, PFOA, PFBS and 6:2FTS).

6.2.2 Summary of selected screening criteria for aquatic ecosystems

The criteria adopted by Cardno Lane Piper for various compounds to protect aquatic ecosystems are:

- *PFOS*: The CCC of 5.1 µg/L is adopted as a 95% protection level for PFOS.
- *6:2 FTS*: The CCC for PFOS (5.1 µg/L) is conservatively adopted as a screening value for 6:2FTS.
- *PFOA*: The CCC of 1,700 µg/L is adopted as a screening value for PFOA
- *AE*: The FTV of 140 µg/L is adopted as a 95% protection level for AE.

6.2.3 Criteria for Sediment

A criterion for sediment of 67 µg/kg ($PNEC_{Sediment}$) was derived in EA (2004). This criterion is a Sediment Quality Guideline (SQG) that was calculated using the equilibrium partitioning method. This method is outlined in ANZECC (2000) to calculate SQGs for non-ionic organic compounds. The method requires that a partitioning coefficient for PFOS from water to sediment (Kd) be calculated. A Kd cannot be calculated for ionic compounds such as PFOS, however a measured value of 8.71 L/kg is available (EA 2004). A SQG is calculated by multiplying a Water Quality Guideline (WQG) by the partitioning coefficient for PFOS (SQG = WQG × Kd). It is not clear how the $PNEC_{Sediment}$ of 67 µg/kg was calculated as PNEC for water is 25 µg/L therefore a SQC = 25 × 8.7 = 217 µg/Kg.

Using this same approach a SQG can be calculated using the 95% criterion of 5.1 µg/L (aquatic ecosystems) for PFOS in water derived by Giesy (2010). A SQG of 44 µg/kg (SQG = 5.1 µg/L × 8.7) was calculated, which is similar to the value derived by EA (2004). It should be noted that Kd for ionic compounds such as PFOS is most likely related to surface chemistry of sediments (rather than organic content). The Kd for clays for example is closer to 33 L/kg (EA 2004). A SQG of 170 µg/kg would be calculated using the Kd for clay. As the SQG for PFOS is influenced by surface chemistry of soils then it should be calculated using a site specific value. Therefore, the SQG of 44 µg/kg is considered a screening criterion only.

Conclusion on relevant criteria for sediment: The $PNEC_{Sediment}$ of 67 µg/kg is adopted by Cardno Lane Piper as a screening criterion for PFOS in sediment.

6.2.4 Criteria for Soils

A $PNEC_{Soil}$ of 373 µg/kg was calculated (EA 2004) based on a short term toxicity result in an earthworm. This criteria was derived by applying an AF of 1000 to the LC_{50} value of 373,000 µg/kg. A lower $PNEC_{Soil}$ was calculated for lettuce of <39 µg/kg however lettuce is not likely to be grown in the Fiskville region. It is noted that this criterion could be up to 16 times higher based on a complete set of toxicity data that is available for biota (Exponent 2005).

Conclusion on relevant criteria for soil compartment: The $PNEC_{Soil}$ of 373 µg/kg for PFOS in soil is adopted as the screening criterion for soil.

6.2.5 Criteria for Mammalian Wildlife

Toxicity data from different 2 year studies in rats exposed to PFOS were used to derive the criteria of 17µg/kg in food ($PNEC_{Oral}$, EA 2004) and 408 ng/g in liver of mammalian species (ENEV, EC 2006)[5]. An AF approach was used to determine both these criteria. The $PNEC_{Oral}$ of 17 µg/kg in food derived by EA (2004) was based on the lowest NOAEL identified in various mammalian studies of 500 µg/kg. This NOAEL is based on liver hypertrophy and an AF of 30 was applied (note that the makeup of this AF used was not defined). A review by Exponent (2005) indicates that this $PNEC_{Oral}$ was not calculated appropriately as:

- Liver Hypertrophy is not indicative of population-based effects as required for deriving PNEC. Instead a NOAEL of 400 µg/kg/day from a reproductive rat study was selected as an appropriate departure point and converted to a NOEC of 8,000 µg/kg.
- The AF included a factor of 10 (assumed to be applied to account for apparent differences in body weight to daily food ingestion ratio). However, this ratio was incorrectly calculated by EA (2004).

This $PNEC_{Oral}$ was recalculated to be 270 µg/kg based on a NOEC of 8,000 µg/kg and AF of 30. The AF of 30 was used as it represented a policy decision (Exponent 2005). RIVM (2010) derived a PFOS criterion (MPC_{Oral}) of 37 $µg/kg_{biota\ w/w}$ for rabbit. The MPC_{Oral} is based on a NOAEL of 100 µg/kg/d (maternal weight gain) identified in a teratogenic study in New Zealand White Rabbit. It was converted to a NOEC by applying a ratio of 33.3 for body weight to daily food intake and an AF of 90 applied. Note that this is the lowest MPC_{Oral} derived by RIVM (2010) from multiple studies, multiple endpoints, 7 species and 26 different departure points (NOAEL range from 100 µg/kg/d to 5,000 µg/kg/d).

The ENEV of 408 ng/g (ENEV) in liver was based on histopathological effects in the liver at the lowest exposure concentrations (ranging from 0.06 to 0.023 mg/kg/day), which corresponded to an LOAEL of 41,000 ng/g in the liver. An AF of 100 was applied to the

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[5] The toxicological studies referred to by EA (2004) and EC (2006) have not been consulted.

LOAEL (10x for laboratory to field extrapolation and 10x for intraspecies variability). Both these criteria are considered screening criteria only.

Conclusion on relevant criteria for mammalian wildlife: The ENEV of 408 ng/g in liver (EC 2006) and the MPC_{Oral} of 37 µg/kg in biota (food) (RIVM 2010) are adopted as screening criteria for mammalian species.

6.2.6 Criteria for Birds

Criteria have been derived based on toxicity studies available for two bird species exposed to PFOS in their diet; the mallard (*Anas platyrhynchos*) and the bobwhite quail (*Colinus virginianus*) (RIVM 2010, Giesy 2010). The criteria include values for PFOS levels in water, biota, bird serum and bird liver and are considered screening values as they were derived using the AF approach.

An MPC_{Oral} of 330 $\mu g/kg_{Biota}$ was derived for both the mallard and the bobwhite quail using a NOEC (1,490 µg/kg and 770 µg/kg respectively), converted using a body weight to dry food intake ratio (6.7 and13 respectively) and an AF of 30 (See Appendix 3, Table A3.1 of RIVM 2010). A Wildlife Value (WV) of 0.047 µg/L was derived for PFOS based on the LOAEL of 770 µg/kg in the quail, an uncertainty factor of 24 and bioaccumulation factor of 9,970 for level IV avian predators (Giesy 2010). Note that these criteria are based on the same study however the departure point is identified as a NOEC by RIVM (2010) and a LOAEL by Giesy (2010).

ENEVs were derived based on PFOS concentrations in serum and liver of birds by EC (2006) using the same species (the mallard and the bobwhite quail). Effects were noted at the lowest exposure concentration of 10ppm in male birds (increased testes size) and female Quails (increased liver weight). Survivability of hatchlings was also reduced but not statistically relevant for Quails exposed to 10ppm. Both the mallards and quail exhibited overt signs of toxicity at higher concentrations (50 ppm and 150ppm) and were euthanized early. An AF of 100 was applied (10x for laboratory to field extrapolation and 10x for intraspecies variability) to the level of PFOS in serum (87,000 µg/L) and liver (6,100 ng/g) of quails in the 10ppm exposure group to give an ENEV of 870 µg/L for serum and 610 ng/g for liver. It was noted that PFOS levels in liver and serum of piscatorial water birds are amongst the highest reported values (EC 2006). A Screening Tissue Threshold of 885 ng/g was derived by Exponent (2005) using the same studies and AF approach. No data is available in this study for PFOS levels in liver or serum of birds.

Conclusion on relevant criteria for birds: The CCC of 0.047 µg/L in water derived for piscatorial birds (Giesy 2010) and the MPC_{Oral} of 330 µg/kg in biota (food) derived for birds (RIVM 2010) are adopted as screening criteria for birds.

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