PFAS Uptake into Biota, and Detailed Human Health and Ecological Risk Assessment: An Australian Defence Base Case Study

Brad Houghton (brad.houghton@senversa.com.au), Katie Richardson (katie.richardson@senversa.com.au), and Kristi Hanson
(Senversa Pty Ltd, Melbourne, Victoria, Australia)

ABSTRACT: Practical, risk-based management of per and poly-fluoroalkyl substances (PFAS)-impacted sites has rapidly become a major focus of contaminated land investigations worldwide, as the scale of response required is likely to be far greater than traditionally seen. This response is confounded by intense community interest and concern for immediate action to manage risk. The level of activity and concern in Australia is fuelled in part by a lack of regulatory certainty around applicable screening criteria and acceptable management measures, and the development of some very stringent draft guideline values (e.g., 0.23 ng/L for freshwater ecosystems, which is below laboratory detection limits and background levels). The use of human health and ecological risk assessment (HHERA) forms a critical component of developing risk responses. Detailed investigations at one site identified impacts from legacy PFOS/PFOA containing AFFF that have migrated off-site through a drainage network to a sensitive wetland and at lower concentrations within off site soil, groundwater, and drainage lines into an important agricultural region. Regulators and the community require careful risk analysis to confirm health, livelihood and reputational risk management requirements.

INTRODUCTION

Defence PFAS Investigations. In May 2016, the Australian Department of Defence commenced a detailed environmental investigation into PFAS, on and in the surrounding area of, RAAF Base East Sale as part of its voluntary program to investigate legacy impacts associated with the use of aqueous film forming foams (AFFF) at their Defence bases in Australia.

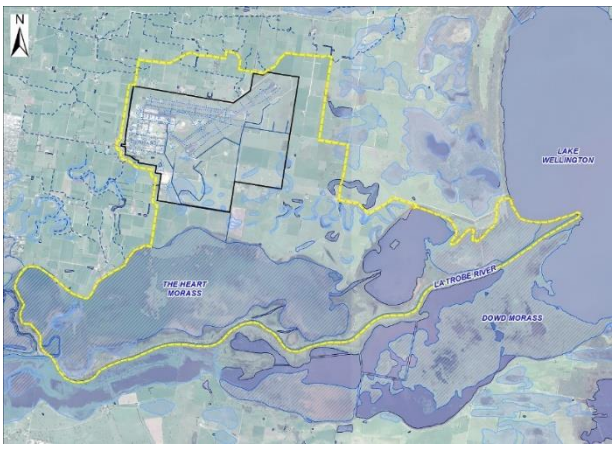


FIGURE 1: Investigation Study Boundary

Legacy firefighting foam containing perfluorooctane sulfonate (PFOS) and perfluorooctanoic acid (PFOA) as active ingredients was used at Defence bases, including at RAAF Base East Sale, for emergency firefighting situations and training. The RAAF Base East Sale environmental investigation is a part of Defence's review of its sites around Australia that used legacy firefighting foam containing PFOS and PFOA as active ingredients.

The objective of the investigation is to identify the nature and extent of PFAS in the environment and any risks to human health or ecosystems. Understanding these risks will assist in developing mitigation and management strategies to minimise exposure, should this be required.

The investigation has been completed as a staged assessment program consistent with the National Environment Protection (Assessment of Site Contamination) Measure 1999 (ASC NEPM). The three main stages of the investigations have been:

- Preliminary Site Investigation
- Detailed Site Investigation and
- Human Health and Ecological Risk Assessment

Detailed investigations at RAAF Base East Sale site identified impacts from legacy PFOS/PFOA containing AFFF that have migrated off site through a drainage network to a sensitive wetland and at lower concentrations within off-site soil, groundwater, and drainage lines into an important agricultural region.

Regulators and the community require careful risk analysis to confirm health, livelihood and reputational risk management requirements.

Site Setting. The site is located in an environmentally sensitive area, close to wetlands of ecological significance, including The Heart Morass to the south, and the Gippsland Lakes RAMSAR site at Lake Wellington to the east. Drainage from the site leads to these areas.

The Heart Morass is also located between two areas of the Gippsland Lakes RAMSAR wetlands, which are wetlands considered to have significant ecological value. In addition, this area is used as a game reserve for duck hunting, fishing, and other recreational purposes and is highly valued by the community.

The site is considered sensitive to the effects of PFAS presence in the environment given that it is located in an agriculturally significant region. All surrounding land is farm zoned and used principally for dairy farming (and associated pasture irrigation), but also cattle (beef) grazing and associated rural residential uses.

The complexity of the geology and hydrogeology at the site controls the movement of groundwater in the area. There are three main shallower water bearing zones that were assessed during Detailed Site Investigations. A thick, impervious clay layer separates these three shallower units from the deep, regionally significant groundwater unit that supplies drinking water in the region.

PRELIMINARY SITE INVESTIGATIONS FINDINGS

A Preliminary Site Investigation (PSI) was conducted to provide a review of historical fire fighting foam use and storage at RAAF Base East Sale. The purpose of this review was to identify PFAS sources, migration pathways and receptors and develop a preliminary conceptual site model.

Key source areas (Figure 2) identified that required investigation included:

- Former maintenance and operations areas where AFFF was stored, and maintenance and testing of fire trucks and ancillary equipment conducted.
- Fire training grounds and waste burial areas, with key areas located within an area leased for cattle grazing.
- Fire stations, AFFF foam and equipment testing areas.

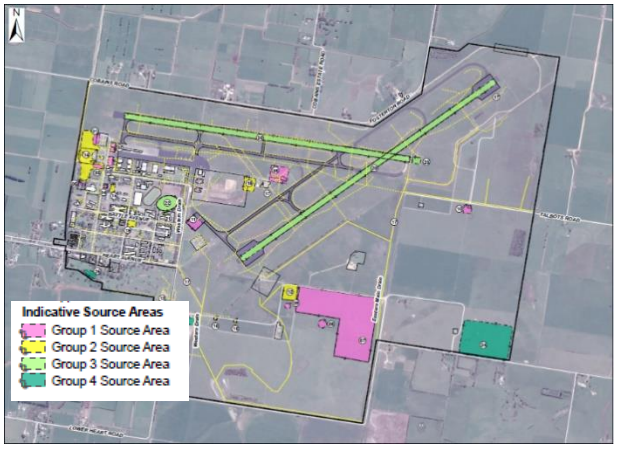


FIGURE 2: PFAS Source Areas

- Stormwater drains that historically received runoff from the key source areas prior to discharging directly from the site to the south, into an area that is a wetland area.

The conceptual model established for the site (Figure 3) was consistent with a typical PFAS CSM associated with AFFF usage for fire-fighting, whereby groundwater and surface water were identified as key pathways for migration into the environment and to humans, with potential receptors being humans on and off-site that are exposed to PFAS through direct access to impacted land and waters, consumption of livestock and fish/game impacted with PFAS from food or water sources, and home grown produce irrigated with PFAS impacted water. Drinking water was not a complete pathway on this Base with groundwater sourced from a deep aquifer not impacted with PFAS and surrounding areas sourcing water from tanks storing rainwater or trucked in water supplies.

DETAILED SITE INVESTIGATION FINDINGS

The Detailed Site Investigation (DSI) involved on- and off-base sampling in soil and grass, surface water, drainage lines and groundwater to assess the nature and extent of PFAS on and near the base.

The key findings from the DSI included:

- Low PFAS concentrations were reported in soil samples across the base. Soil samples collected on private properties off base recorded very low concentrations of PFAS, many times lower than the adopted human health screening criteria for a residential setting.
- Elevated concentrations of PFAS were identified in on-base shallow groundwater and drainage line surface waters. Lower concentrations in groundwater and surface water were identified off base.
- The main pathway for off-base migration of PFAS is via surface water drainage features, and to a lesser extent groundwater.
- Concentrations of PFAS in surface water and sediment off site established the need for additional biota data to be collected for direct measurement of PFAS concentrations and uptake within plants and animals.

TABLE 1: PFAS Sample Results

Sample Type & Location	PFOS+PFHxS Concentration (mg/kg or µg/L)		
	Low	High	Median
SURFACE WATER			
Drainage Lines - On-Site	<LOR	283	3.39
Drainage Lines - Off-site	0.005	2.49	0.19
The Heart Morass - Off-site	0.004	0.74	0.29
Background Rivers - Off-site	<LOR	0.01	N/A
SEDIMENT			
Drainage Lines - On-Site	0.0002	0.8765	0.0384
Drainage Lines - Off-site	0.0003	0.3203	0.0037
The Heart Morass - Off-site	<LOR	1.93	0.0595
GROUNDWATER			
Incidental Contact - Shallow (<2m GW Depth)	<LOR	8,874	3.01
Shallow Upper Aquifer - On-site	<LOR	8,874	2.97
Intermediate Upper Aquifer - On-Site	<LOR	523	5.135
Deep Upper Aquifer - On-Site	<LOR	0.94	N/A
Monitoring wells - Off-site	<LOR	0.62	N/A
Private Bores - Off-site	<LOR	0.24	N/A
SOIL			
Private Properties - Off-site	<LOR	0.0246	0.0018
Operational Areas - On-Site	<LOR	84/440	0.0454
Grazing Areas - On-Site	<LOR	16.95	0.0188
Sensitive Use Areas - On-Site	<LOR	0.01	0.0014
GRASS			
Operational/Open Space - On-Site	<LOR	12	0.74
Grazing - On-Site	<LOR	0.044	0.0054
Private Properties - Off-site	<LOR	0.0018	N/A

N/A - Number of detections is 5 or less

Results from the DSI confirmed the key receptors and pathways requiring assessment in a Human Health and Ecological Risk Assessment (HHERA).

Human receptors/pathways requiring further assessment:

- Worker direct contact with surface water in drains and/or shallow groundwater; and
- Consumption of agricultural products or wildlife/game into which PFAS may have bioaccumulated.

Ecological receptors requiring further assessment are:

- Predators (e.g. birds) who may feed on aquatic flora/fauna within open drains or other surface water bodies;
- On-base terrestrial receptors within source areas; and
- Aquatic flora and fauna within The Heart Morass and, to a lesser extent, the Latrobe River.

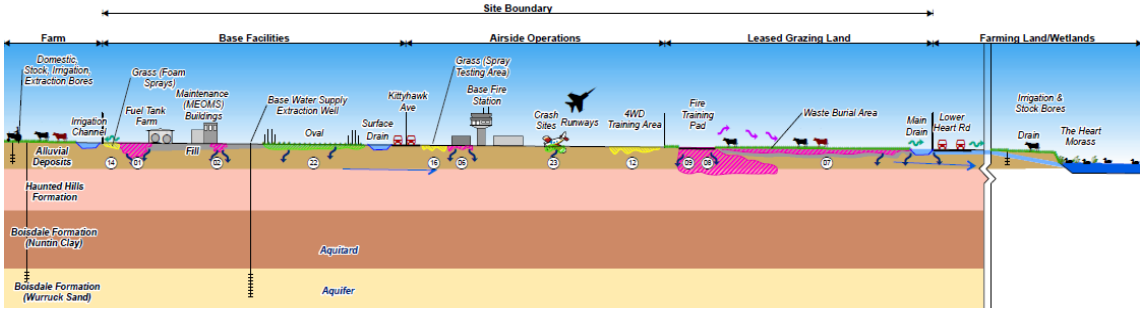


FIGURE 3: Conceptual Site Model

BIOTA SAMPLING

Detailed biota sampling and analysis were completed to provide data to support the HHERA. This included the collection of the following biota samples from The Heart Morass wetland and other surface waters (including on-base ponds and main drain), and additional grass and water sources on private agricultural properties considered to represent the land use scenarios for livestock assessment.

- Fish, eels and ducks.
- Aquatic Invertebrates and aquatic plants.

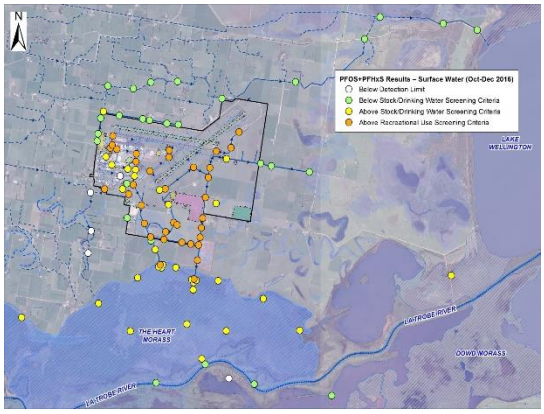


FIGURE 4: Surface Water PFAS Concentrations

The results of the biota sampling were utilised within the HHERA together with the results of soil, groundwater and surface water investigations to assess risks via key receptor pathways, including:

- Potential risks to humans consuming wildlife/game.
- Potential risks to humans consuming livestock meat, offal and milk.
- Potential Ecological receptors higher up the food chain, who may feed on organisms into which PFAS has bioaccumulated

Even though low surface water concentrations were reported, the elevated concentrations measured in aquatic biota were consistent with those predicted (based on measured water concentrations, and worldwide literature bio-concentration factors). A total bioaccumulation factor of 12,900 L/kg from water into fish (i.e. concentration in fish flesh (µg/kg) / concentration in water (µg/L)) was used in the derivation of freshwater screening levels for a pathway of fish ingestion (CRC CARE, 2017). RIVM (2010) utilised a similar value in their screening level derivation. The BAF is calculated as the biomagnification factor (BMF), which considers concentration in lower level organisms relative to water, multiplied by a bioconcentration factor (BCF) to account for accumulation through the food chain.

TABLE 2: Estimated and measured fish concentrations using a BAF of 12,900 L/kg

Water Concentration	Estimated Fish Concentration	Measured Fish Concentration
0.74 µg/L	~9,500 µg/kg	Up to 12,000 µg/kg
0.3 µg/L	~4,000 µg/kg	1,300-2,000 µg/kg (up to 6,400)
0.01-0.072 µg/L	~130-930 µg/kg	<200 µg/kg

On this basis, the measured concentrations in aquatic fish biota could be reasonably attributed to the impacts sourced from the site.

CATTLE RISK ASSESSMENT

Located within an agricultural region, the East Sale RAAF base is surrounded by properties that primarily farm beef and dairy cattle. Surplus Defence land is also leased for the grazing of beef cattle, with this land including a former fire training area and waste burial area.

To estimate the level of risk to consumers of animal and animal products (i.e. meat, offal and milk) from cattle raised in the area, it was necessary, in the absence of measured PFAS concentrations, to estimate the concentrations of PFAS in these products.

A number of studies have demonstrated clear relationships between blood plasma concentrations and concentrations in milk and meat for dairy cows. This means PFAS concentrations can be measured in cattle blood serum, and then experimentally derived factors used to estimate the concentrations in meat, offal and milk from the concentrations in blood plasma.

However, on this site, blood plasma data for cattle in the area were unavailable. It was therefore necessary to additionally estimate the concentrations in blood plasma from the likely intake in cattle diet from the site. This was performed by using the measured concentrations from grass and water used for stockwatering, and in soil which cattle may incidentally ingest while grazing, and applying a factor to estimate plasma concentrations from the estimated intake.

Based on a detailed literature review, the following cattle uptake and distribution factors were developed:

- **Plasma uptake factors**, to allow the estimation of plasma concentrations in cattle from the estimated intake in cattle diet. The selected uptake factor estimates steady-state plasma concentrations, which represent the maximum plasma concentrations which could be reached following extended exposure. This is a conservative approach, which accounts for situations where cattle remain within PFAS-affected areas for extended periods, and may overestimate plasma concentrations where the exposure timeframe within PFAS-affected areas is limited.
- **Meat–plasma and milk–plasma distribution factors**, to allow the estimation of milk and meat concentrations from estimated plasma concentrations.

Concentrations in meat, offal and milk have been estimated based on estimated intakes (i.e. from the assumed consumption rates of grass, soil and water and the site-measured concentrations of PFAS in these media), together with these uptake factors.

To estimate potential risk to home consumers, estimated concentrations in produce were compared to Australian food safety (FSANZ) triggers. For a public consumption scenario (for product sold commercially) estimated intakes (based on the estimated concentrations, and produce comprising a certain proportion of an individual's diet) were compared to tolerable daily intake (TDIs) as defined in FSANZ (2017), from which background intakes are subtracted to define the tolerable intake. The ratio of intake to acceptable intake is referred to as the hazard quotient (HQ).

The Hazard Quotient (HQ) is defined as:

HQ = CDI/(TDI-Background)

Where:
HQ = Hazard Quotient
CDI = Chronic Daily Intake (mg/kg/day)
TDI = Tolerable Daily Intake mg/kg/day)

The results of the risk modelling for livestock consumption are presented below:

Scenario		Meat			Offal			Milk		
		Estimated PFOS+PFHxS concentration in meat (µg/kg)	FSANZ trigger value for meat (µg/kg)	Hazard Quotient (HQ) (public consumption)**	Estimated PFOS+PFHxS concentration in offal* (µg/kg)	FSANZ trigger value for offal (µg/kg)	Hazard Quotient (HQ) (public consumption)**	Estimated PFOS+PFHxS concentration in milk (µg/kg)	FSANZ trigger value for milk (µg/kg)	Hazard Quotient (HQ) (public consumption)**
On-site	All grazing area	125	3.5	0.5	2585	96	1.1	*8.8*	0.4	*0.1*
	East of drain	23		0.09	481		0.2	*1.5*		*0.02*
Off-site	Irrigation lines/drains	2.7		0.01	55		0.02	0.2		0.005
	Bore/dam water	2.4		0.01	50		0.02	0.2		0.003

Note: Estimated meat, offal and milk concentrations has been developed using site derived soil, grass and water concentrations
* Offal concentration is taken as the higher of the concentrations estimated from liver and kidney
2.70E-01 Estimated risks are in italics for currently inactive pathways (i.e. milk from on-site)
2.70E-01 Estimated risk exceeds FSANZ trigger value, or hazard index >1, indicating further assessment of potential expoure scenario or additional data required.

** The higher of the HQ estimated for adult and child exposures is presented. Mean consumption rates assumed. The assumed proportion of each foodstuff in the diet which is assumed to come from the Investigation Area is summarised below.

Assumed proportion of produce in diet after entering wider public food chain	**Meat**	**3%**	Based on conservative assumption that someone purchases single large cut of meat to be made into multiple family meals, of which 1kg (0.5kg for a child) is for their sole consumption over several meals
	Offal	**2%**	Based on conservative assumption that someone purchases single supermarket offal packet (500g) from a single animal to be made into multiple family meals, of which half (250g) is for their sole consumption over several meals.
	Milk	**0.8%**	Assumes 2L from Investigation Area; Likely to be much lower than this given the mixing which will occur.

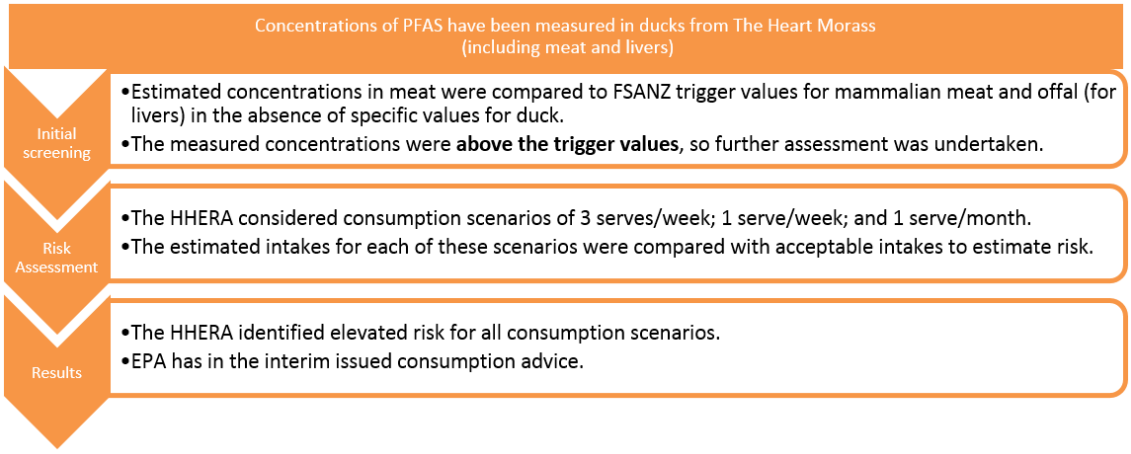
The HHERA demonstrated that potential risks to home consumers or public consumers of meat, milk or offal raised off site were low and acceptable.

Further assessment (and direct measurement of cattle serum concentrations where available) is needed to better understand the potential risks associated with home consumption and public consumption of livestock raised on the Defence-owned grazing land.

DUCK RISK ASSESSMENT

To the south of the East Sale RAAF Base is The Heart Morass, a permanent, freshwater marsh that supports significant breeding populations of waterbirds, including duck species targeted for hunting for human consumption. Therefore, the HHERA assessed potential risks to recreationally hunted game consumers.

It is noted that ducks are migratory in nature and present across wide areas of Australia and are likely to source their diet widely (not just from The Heart Morass). As such, there is a level of uncertainty around whether the measured PFAS concentrations in ducks are related solely to exposure in The Heart Morass, or to other potential sources in a wider area. However, the sampling approach was to obtain ducks representative of a recreational hunter's typical catch in The Heart Morass, where they spend at least some of their time.



Ducks were collected and sampled for different body parts to assess concentration of PFAS within the different meats that may be consumed, including the skin and also the whole duck to assess ecological risks for consumption by higher order predators (Figure 5). The distribution of PFAS concentrations established that they were similar in meat and skin, but much higher in the liver of the ducks.

The sampling also established that there was a correlation between the meat and skin, with concentrations in skin approximately 50% greater than those in the meat (Figure 6). Therefore these data were used in the consumption scenarios to provide some guidance on whether consumption risks could be reduced if meat with skin off was consumed.

The correlation between meat and liver concentrations (Figure 7), indicates that there is a clear relationship, according to which liver concentrations are approximately 9 times the corresponding breast meat concentrations.

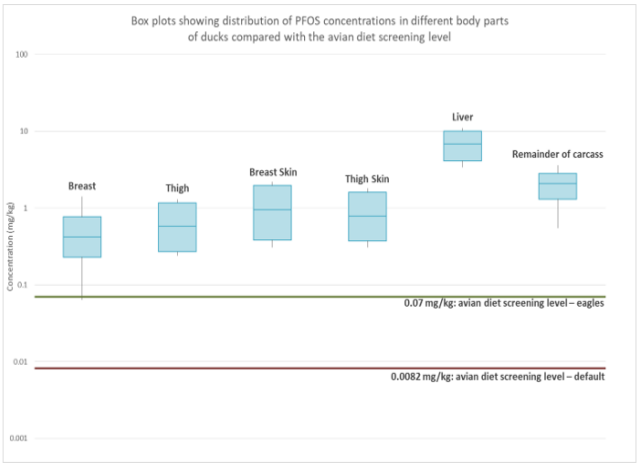


FIGURE 5: Box Plot of PFOS in Duck Body Parts

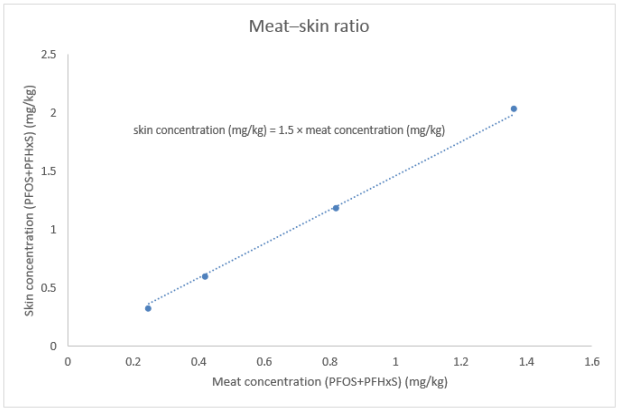


FIGURE 6: Duck Meat-Skin Concentration Ratio

The results indicate that measured concentrations of PFOS+PFHxS in the breast meat and livers of ducks are approximately 100 times above the respective FSANZ trigger values.

In addition to direct comparison against the FSANZ trigger values (which conservatively assume daily consumption), the potential risks associated with a range of possible consumption scenarios reflecting the likely range in frequency of duck

consumption by recreational hunters (i.e., consumption of 3 serves/week, 1 serve/week and 1 serve/month) have been assessed (Figure 8).

Based on these estimated intakes, the consumption risks were estimated by direct comparison of the daily intake of PFOS+PFHxS with the respective tolerable daily intake (TDIs) as defined in FSANZ (2017), from which background intakes are subtracted to define the tolerable intake from consumption of duck. The ratio of intake to acceptable intake is referred to as the hazard quotient (HQ).

Risks associated with the consumption of ducks from The Heart Morass are elevated, even when infrequent consumption (i.e., 1 serve/month) is assumed.

There is concluded to be an elevated risk associated with the home consumption of duck meat and duck liver recreationally hunted from The Heart Morass even at low consumption rates (i.e., 1 serve of duck/month).

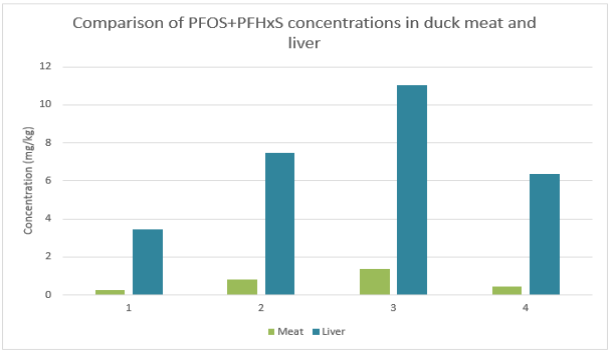
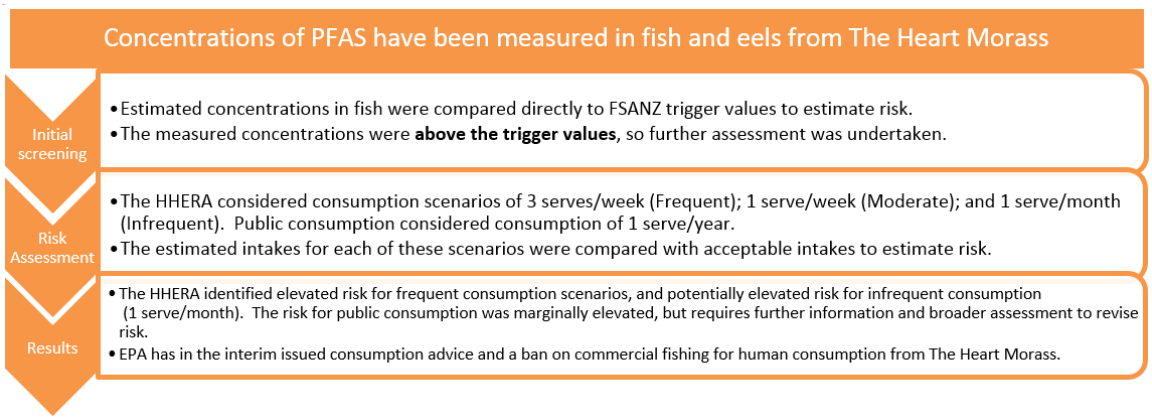


FIGURE 7: Duck Concentrations in Meat and Liver

FIGURE 8: Hazard Quotient Box Plots for Duck Consumption Scenarios

FISH AND EEL RISK ASSESSMENT

The aim of the sampling was to collect a range of fish (species, age and size) that were representative of fish caught recreationally and commercially within The Heart Morass, targeting species including: bream, eel, carp, mullet, and perch. However, the conditions within the wetlands at the time of sampling meant that only commercially caught species of eels and carp, and one species of recreationally caught fish (Tupong), were able to be collected.



All PFOS+PFHxS concentrations in fish and eels were recorded above the relevant screening levels (Figure 9). Therefore, there is concluded to be an elevated risk associated with daily consumption of fish from The Heart Morass.

In addition to direct comparison against the FSANZ trigger values (which conservatively assume daily consumption), the potential risks associated with a range of possible consumption scenarios reflecting the likely range in frequency of fish consumption by recreational fishers (i.e., consumption of 3 serves/week, 1 serve/week and 1 serve/month) have been assessed (Figures 10a and 10b). To assess a commercial fishing scenario, it is assumed that at most 1 serve/year would be sourced from The Heart Morass. For food entering the public supply, it is not considered plausible that an individual would source a significant proportion of the fish in their diet from The Heart Morass. For this scenario it has been assumed that for an individual, at most 1 serve/year (150g for adults; 75 g from children) would be sourced from The Heart Morass.

Based on these estimated intakes, the consumption risks were estimated by direct comparison of the daily intake of PFOS+PFHxS with the respective tolerable daily intake (TDIs) as defined in FSANZ (2017), from which background intakes are subtracted to define the tolerable intake from consumption of fish. The ratio of intake to acceptable intake is referred to as the hazard quotient (HQ).

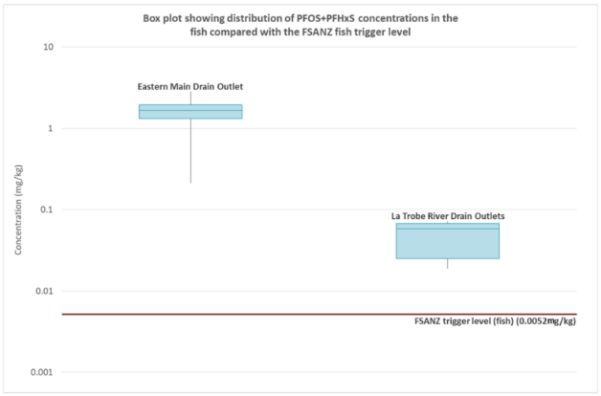


FIGURE 9: PFOS Concentrations in Fish and Eels compared to Trigger Levels

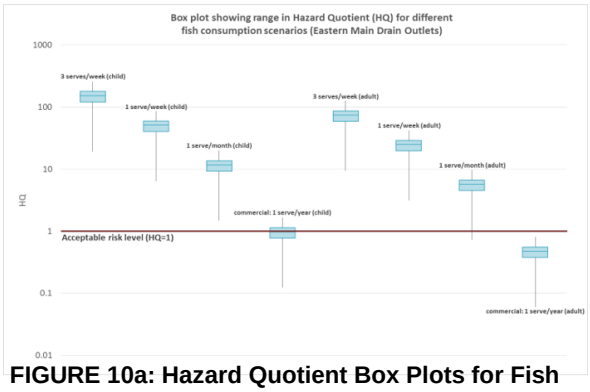


FIGURE 10a: Hazard Quotient Box Plots for Fish Consumption Scenarios

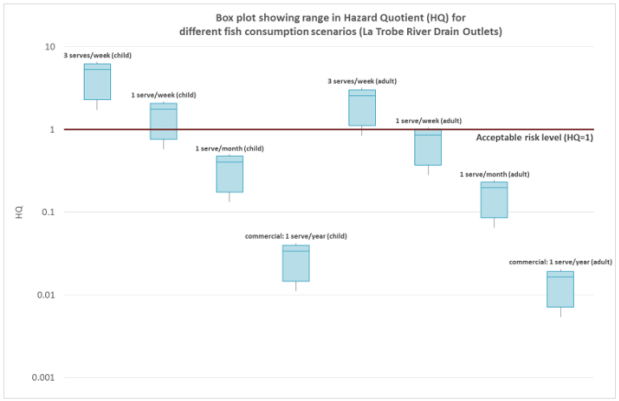


FIGURE 10b: Hazard Quotient Box Plots for Fish Consumption Scenarios

Recreational Fishing: There is concluded to be an elevated risk associated with the home consumption of fish caught from the area of the Eastern Main Drain Outlet, even at low consumption rates (i.e. 1 serve of fish/month). It is noted that there is limited public access to this area of The Heart Morass, as it adjoins privately held land.

There is concluded to be an elevated risk associated with the home consumption of fish caught from the area of the Latrobe River Drain Outlets, when moderate-to-high consumption rates (1 -3 serves/week) are assume d. However, the estimated risks are low and acceptable for less frequent consumption (i.e. 1 serve/month).

Commercial Fishing: Risks are assessed to be marginally elevated based on the concentrations in eel and tupong measured at the Eastern Main Drain Outlet. It is at

least plausible that an assessment of risks from eel and tupong consumption which is based on concentrations measured at the Eastern Main Drain Outlet is likely to be conservative for The Heart Morass as a whole, given the elevated surface water concentrations measured in this area. However, It is understood that larger fish (including eels and carp) than those currently sampled are taken commercially. Based on the available data, it cannot be excluded that PFAS concentrations in these larger, older fish (given their increased lifespan and increased PFAS exposure potential) could be higher than those currently measured.

Risks are approximately 20 to 100 times below the acceptable level based on the concentrations measured in carp at the Latrobe River Drain Outlets. Even based on a limited dataset, there is therefore a relatively high level of certainty that the potential risks associated with public consumption of commercially caught fish carp from this area of The Heart Morass are low and acceptable. However, further data would be required to undertake a conclusive assessment of the potential risks associated with public consumption of carp from other areas of the Heart Morass (where PFAS water concentrations are higher), or other species in this area of The Heart Morass. Therefore, while the current data for carp from this area indicates potential risks from public carp consumption are likely to be low and acceptable, it is not possible to extrapolate this conclusion more broadly (in terms of location or species), and potentially elevated risks for carp in other areas of The Heart Morass, or other species in this area, cannot be excluded.

It is noted that commercial fishing from The Heart Morass is known to include “ranching”, where young eels from The Heart Morass are transferred to freshwaters in other areas (for example, for a period of months) to increase weight before being harvested for consumption. Fish eliminate (lose) PFAS from their bodies relatively rapidly, with variable elimination half lives in different fish species: 13 to 20 days (observed in juvenile rainbow trout), and 133 to 152 days (bluegill) (Giesy et al., 2010). On this basis, where ranching is practiced, potential risks are likely to be reduced. However, there is uncertainty around a number of factors, including the elimination half-life specifically for eels; the range in concentrations in eels across The Heart Morass (due to varying location, weight and age); and the exact nature of ranching practices. Further data would be required to facilitate an assessment of whether ranching practices (where adopted) would be expected to reduce risks associated with a public consumption pathway to a low and acceptable level.

On this basis, it is not considered possible to exclude elevated risks based on a pathway of public consumption of fish from The Heart Morass.

ECOLOGICAL RISK ASSESSMENT

The Heart Morass was historically significantly degraded due to widespread clearing, heavy grazing, poor water management, acid sulphate soils and salinity impacts, resulting in the wetland drying completely for the first time in 2006 (WGCMA, 2016). Rehabilitation of the area has occurred since 2006, with a subsequent improvement in the health and function of the local ecology. Following the recent rehabilitation works across The Heart Morass, over 30,000 waterbirds from a range of species have returned to the wetland, including the Glossy Ibis, Freckled Duck, Intermediate Egret, White-bellied Sea Eagle and Plumed Whistling Duck (DELWP, 2015). The eastern extents of the Heart Morass are within a RAMSAR wetlands area and considered to have significant ecological value.

Ecological risk assessment, including biomagnification and bioconcentration food web risk analysis, was completed through direct comparison of water concentrations to

ecological screening levels (to assess direct toxicity), and through food web considerations including comparison of aquatic biota and duck concentrations to avian diet screening levels.

The ecological risk assessment made the following conclusions:

- Reported surface water PFOS concentrations in The Heart Morass were above the screening level for assessment of adverse effects due to direct contact exposure by aquatic species and bioaccumulation within aquatic ecosystems (draft revised ANZECC/ARMCANZ water quality guidelines).
- Reported PFOS concentrations in aquatic biota (including plants, invertebrates and fish/eels) and ducks exceeded relevant dietary screening concentrations for the protection of a range of relevant bird receptors (Environment Canada [EC] avian diet screening levels, and adjusted levels for different representative bird species).

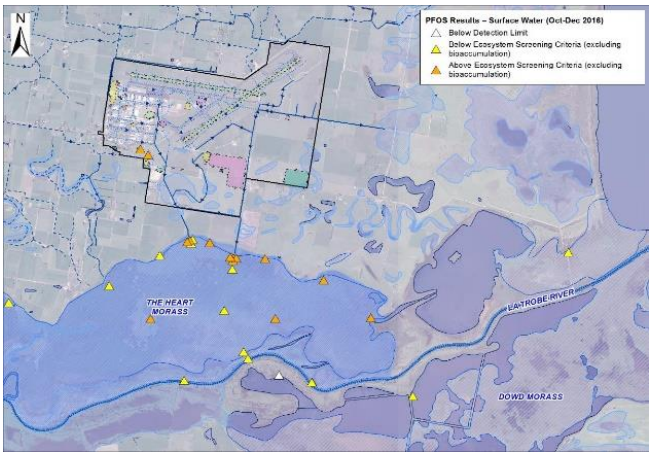


FIGURE 11: PFOS Concentrations in Surface Water – Ecological Screening Levels

Overall, it is not considered possible to exclude potential adverse effects to ecological receptors within The Heart Morass, although it is emphasised that for species which source only a portion of their diet from within the Investigation Area, risks may be lower than indicated in this assessment, however more data is required. The identification of potentially elevated risks does not necessarily indicate that there will be adverse effects, but instead that management of risks and/or further investigation/assessment may be warranted.

The measured PFAS concentrations in ducks exceed avian diet screening levels; however, it is noted that these ducks themselves are migratory and are likely to source their diet widely (not just from The Heart Morass); as such, while the measured concentrations pose elevated risks to predators eating these ducks as part of their diet, there is a level of uncertainty around whether the measured PFAS concentrations in ducks relate solely to exposure in The Heart Morass, or to other potential sources in the area.

There is currently insufficient data to fully assess potential risks to aquatic ecosystems in natural surface waters up-stream or down-stream of The Heart Morass, or to provide a full assessment of the variation in concentrations within The Heart Morass. This is because the assessment focussed on assessing the risks from those areas where the potential for exposure is highest. While risks were elevated for all biota collected from The Heart Morass, the concentrations in fish collected from drains between The Heart Morass and the Latrobe River were lower than in other locations of The Heart Morass; the risk to avian predators remained elevated for these fish, but only marginally so for certain receptor types (e.g. eagles). The most elevated concentrations were identified in biota collected from the vicinity of the site's main surface water discharge outlet, the Eastern Main Drain. These results provide some indication that the potential ecological risks may be variable within The Heart Morass and may reduce downstream of The Heart Morass. This could be further understood as part of wider ecological investigations and assessment.

However, the risks to ecosystems are likely to remain elevated for at least some species that are more localised, and refinement of the ecological risk assessment is unlikely to be warranted with available data. It raises the question with PFAS investigations and risk assessment - are detailed food web assessments, that consider multiple specific species, taxonomic groups and their range, warranted for ecological risks where a broad approach may be proportionate and appropriate to draw overall conclusions regarding ecological risks to higher order predators? or where an elevated risk to receptors is identified within an investigation boundary is progressing straight to mitigation and management of the source of the risk (in this case direct surface water discharge), with a monitoring program to demonstrate improvement in the environment before risk refinement, money better spent? In this case, an ability to communicate the outcomes of the ecological risk to the regulators and getting agreement that additional species or wider area sampling is not warranted at this stage will see time and money better spent on management of the PFAS sources with the objective of ecological improvement

PFAS MANAGEMENT

The next phase of the project involves the assessment and selection of management measures that can be implemented to offer protection to the human health and ecological receptors associated with the site and surrounds. Given the persistence of PFAS, the value of the ecosystem, and the lack of effective or acceptable disposal or destructive technologies, wide-scale source removal is unlikely to provide an acceptable or pragmatic solution. Management is therefore likely to incorporate a combination of source control, exposure pathway controls and restriction of activities where required to reduce risks.

This is consistent with the Victorian EPA's focus, which is on preventing the potential for off-site environmental and human health impacts from PFAS through source control (EPA, 2017) and recently released national guidance on PFAS management – PFAS National Environmental Management Plan (HEPA, 2018), which allows for the implementation of a management strategy and associated environment plan for onsite management. This is regarded as applicable where the site investigation and risk assessment indicates that remediation would have no net environmental benefit at the local site, or within the broader catchment would have a net adverse environmental effect (e.g. determined via a site-specific risk assessment), or where management of exposure pathways rather than treating at source would be acceptable particularly as an interim measure while other options are considered. An onsite management strategy would be appropriate provided that:

- unacceptable risks to offsite ecosystems and/or human health exposure such as by surface water or groundwater migration is not occurring or is managed
- the land owner agrees and has sufficient expertise and financial capacity to implement and maintain the management measures, the polluter should monitor and report on the efficacy of the measures for the duration of the activity
- the environmental regulators implement appropriate statutory tools for requiring compliance, including the ongoing provision of information (for example, publicly available fishery advice), with such strategies and ensuring community right to know.

This national guidance document was released in January 2018. Defence's management strategy for their sites (in place prior to release of the guidance) is consistent with the process recommended in this guidance document, demonstrating that they are leading the way in PFAS investigation and management within Australia.

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