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

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Introduction

Practical, risk-based management of per and poly-fluoroalkyl substances (PFAS)-impacted sites have 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.

Background

Defence PFAS Investigations

Legacy firefighting foam containing perfluorooctane sulfonate (PFOS) and perfluorooctanoic acid (PFOA) as active ingredients was used at Australian Department of Defence bases, including at RAAF Base East Sale, for emergency firefighting situations and training.

In May 2016, Defence commenced PFAS investigation with the objective 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.

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 (Figure 2) 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.

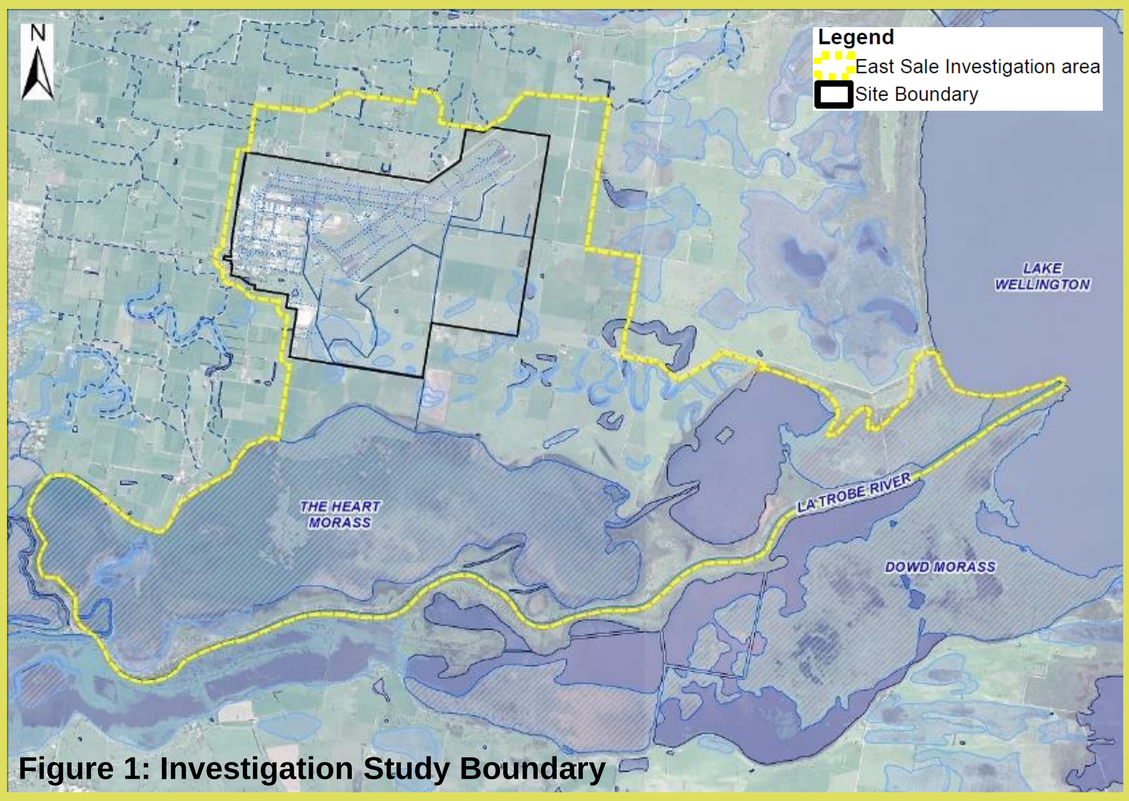


Figure 1: Investigation Study Boundary

Site Setting

Located in an environmentally sensitive area, close to wetlands of ecological significance, including The Heart Morass to the south

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 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 assessed. A thick, impervious clay layer separates these three shallower units from the deep, regionally significant groundwater unit that supplies drinking water in the region.

Investigation Findings

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 human receptors 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 and ecological receptors such as higher order predators and aquatic flora and fauna. 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.

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
GROUNDWATER			
Incidental Contact - Shallow (<2m)	<LOR	8,874	3.01
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

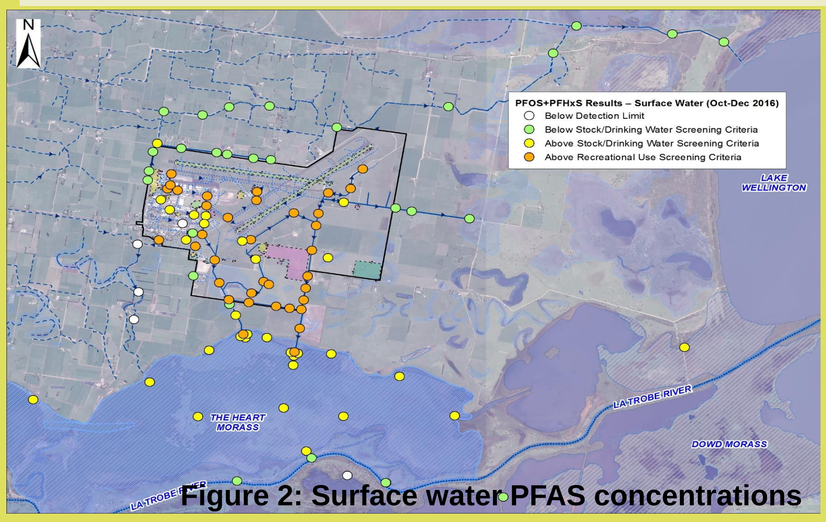


Figure 2: Surface water PFAS concentrations

Biota Sampling

Detailed biota sampling and analysis was 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.

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 3: 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.

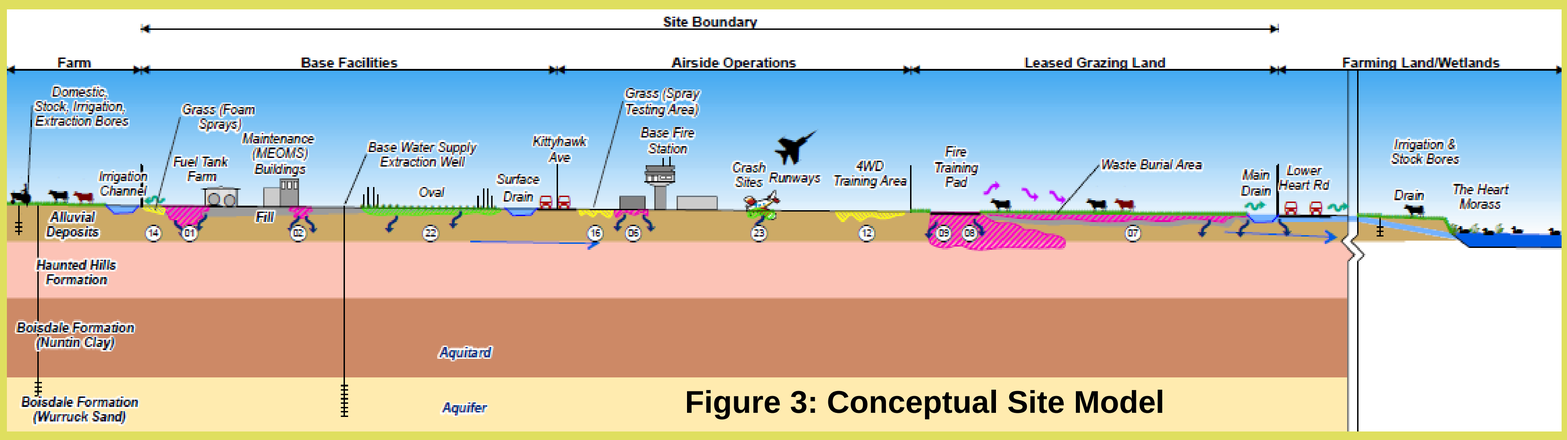


Figure 3: Conceptual Site Model

Duck Risk Assessment

To the south of the East Sale RAAF Base is The Heart Morass - a permanent, freshwater marsh, which 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.

Concentrations of PFAS have been measured in ducks from The Heart Morass (including meat and livers)

Initial screening
- Estimated concentrations in meat were compared to FSANZ trigger values for mammalian meat and offal (for livers) in the absence of specific values for duck.
- The measured concentrations were **above the trigger values**, so further assessment was undertaken.

Risk Assessment
- The HHERA considered consumption scenarios of 3 serves/week; 1 serve/week; and 1 serve/month.
- The estimated intakes for each of these scenarios were compared with acceptable intakes to estimate risk.

Results
- The HHERA identified elevated risk for all consumption scenarios.
- EPA has in the interim issued consumption advice.

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. Therefore this data was 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, indicates that there is a clear relationship, according to which liver concentrations are approximately 9 times the corresponding breast meat concentrations.

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.

Based on the 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).

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)

Risks associated with the consumption of ducks from The Heart Morass are elevated, even when infrequent consumption (i.e. 1 serve/month) is assumed (Figure 5).

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).

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.

Concentrations of PFAS have been measured in fish and eels from The Heart Morass

Initial screening
- Estimated concentrations in fish were compared directly to FSANZ trigger values to estimate risk.
- The measured concentrations were **above the trigger values**, so further assessment was undertaken.

Risk Assessment
- The HHERA considered consumption scenarios of 3 serves/week (Frequent); 1 serve/week (Moderate); and 1 serve/month (Infrequent). Public consumption considered consumption of 1 serve/year.
- The estimated intakes for each of these scenarios were compared with acceptable intakes to estimate risk.

Results
- The HHERA identified elevated risk for frequent consumption scenarios, and potentially elevated risk for infrequent consumption (1 serve/month). The risk for public consumption was marginally elevated, but requires further information and broader assessment to revise risk.
- EPA has in the interim issued consumption advice and a ban on commercial fishing for human consumption from The Heart Morass.

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

Based on the estimated intakes, the consumption risks were estimated using the same method for ducks.

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 (Figure 6a), even at low consumption rates (i.e. 1 serve of fish/month).

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 (Figure 6b), when moderate-to-high consumption rates (1 -3 serves/week) are assumed. 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.

Risks are approximately 20 – 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.

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. It is not considered possible to exclude elevated risks based on a pathway of public consumption of fish from The Heart Morass.

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 4). The distribution of PFAS concentrations established that they were similar in meat and skin, but much higher in the liver of the ducks.

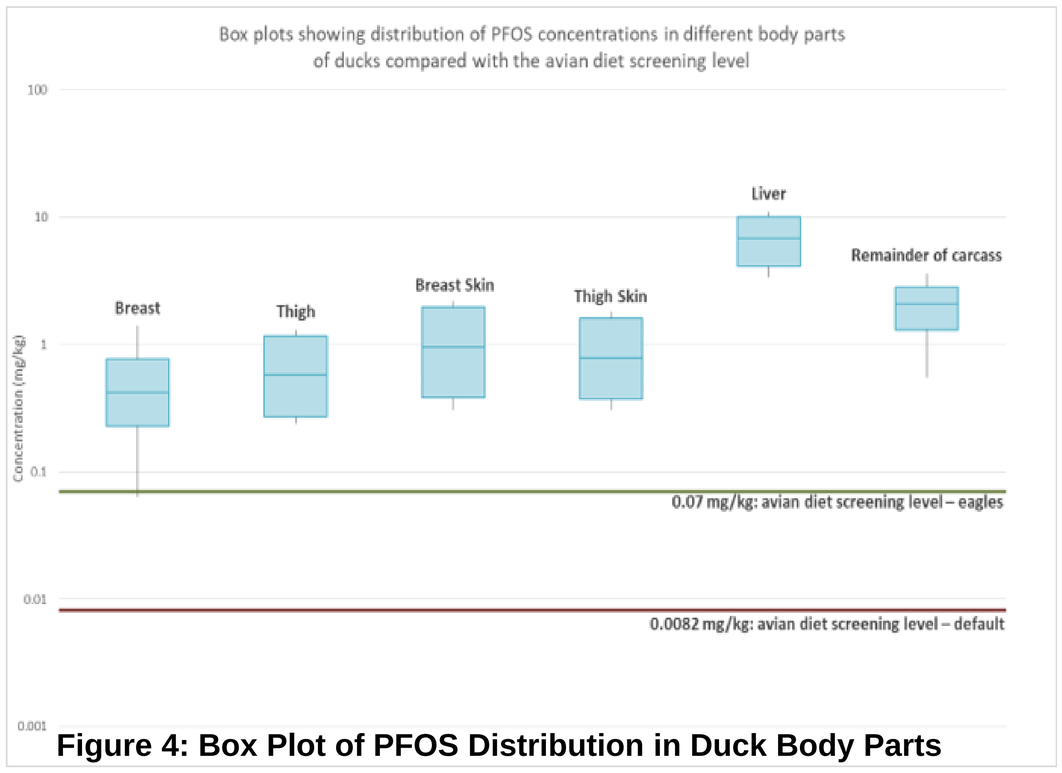


Figure 4: Box Plot of PFOS Distribution in Duck Body Parts

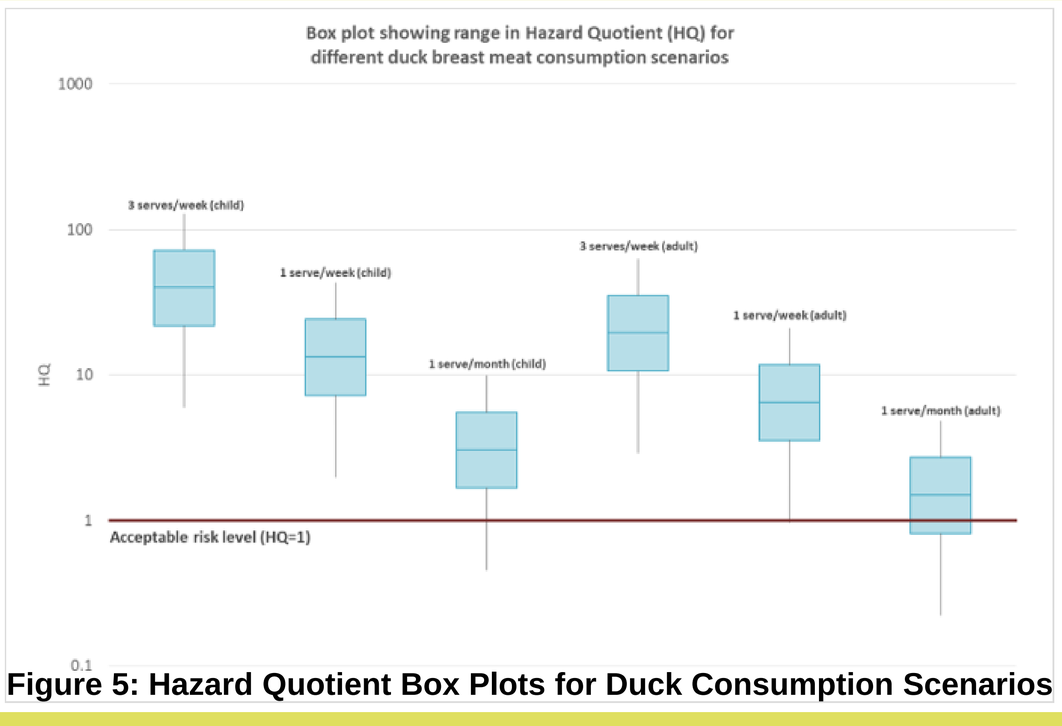
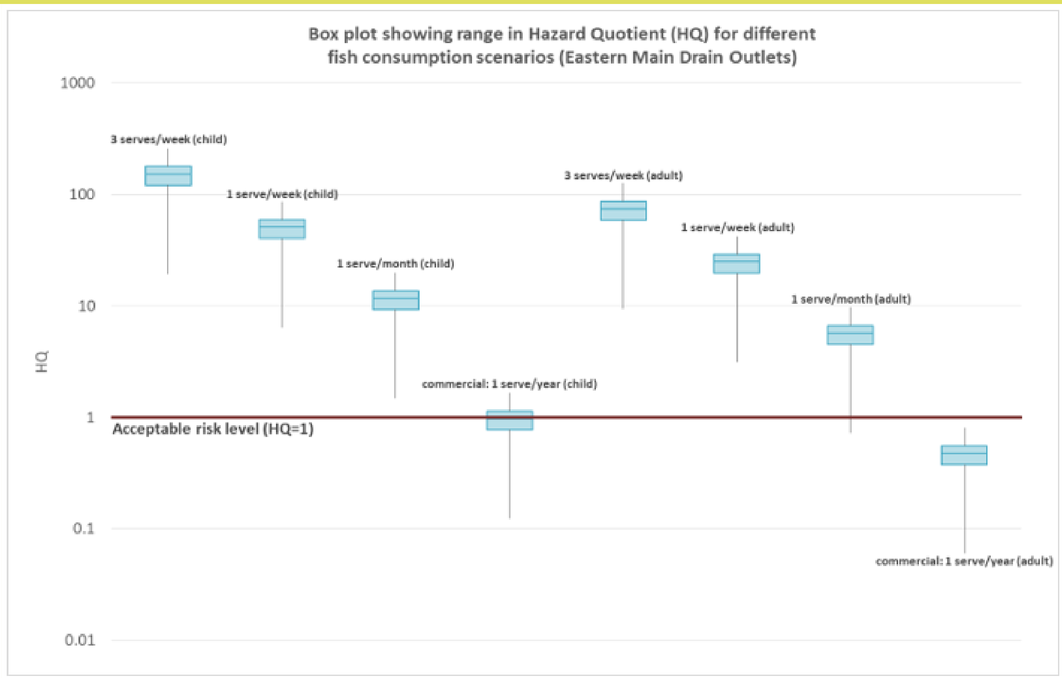


Figure 5: Hazard Quotient Box Plots for Duck Consumption Scenarios



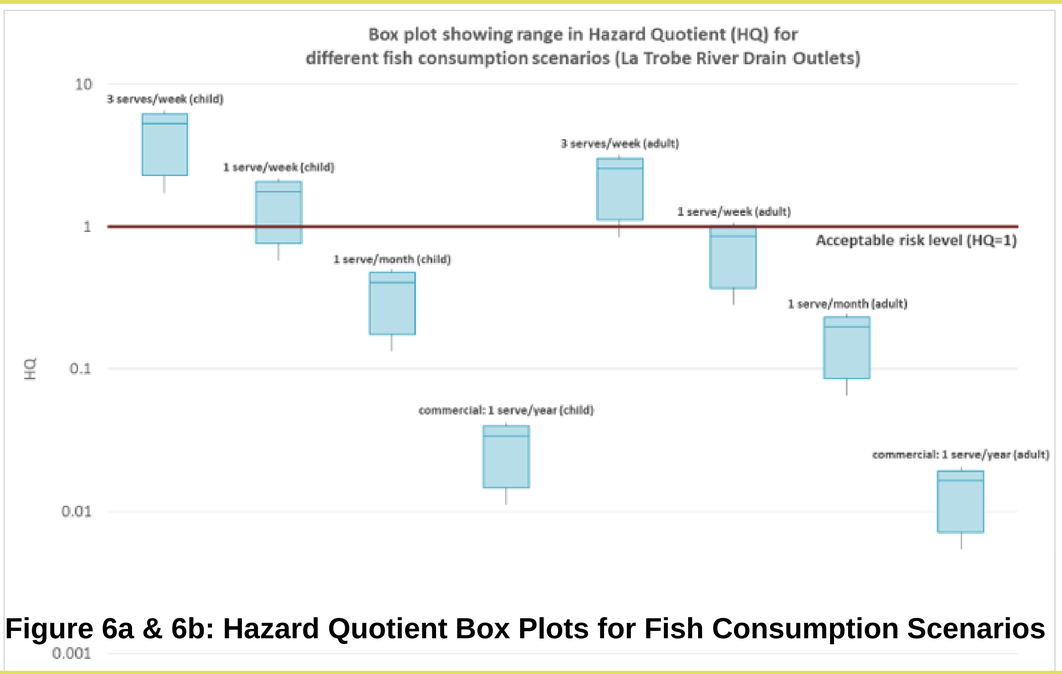


Figure 6a & 6b: Hazard Quotient Box Plots for Fish Consumption Scenarios

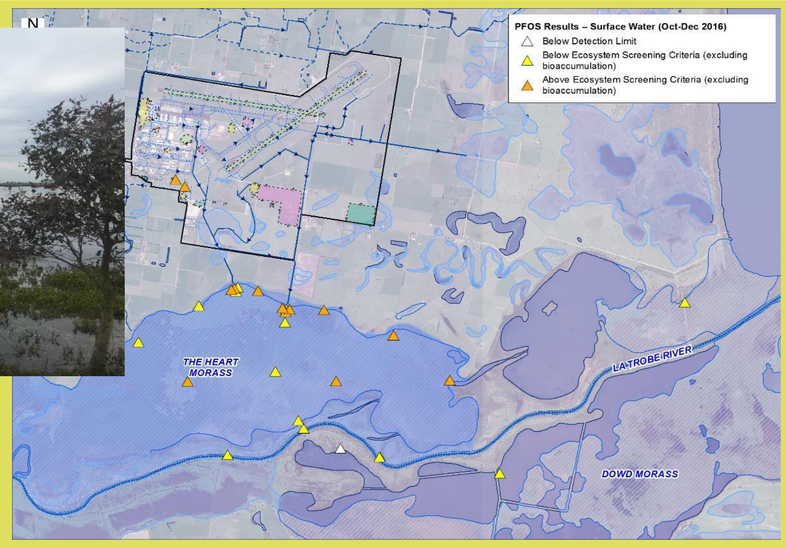
Ecological Risk Assessment

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. 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).



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 further assessment and 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.

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.

In order 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. On this site, blood plasma data for cattle in the area was 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.

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

Scenario		Meat: Estimated PFOS+PFHxS concentration in meat (µg/kg)	Meat: FSANZ trigger value for meat (µg/kg)	Meat: Hazard Quotient (HQ) (public consumption)**	Offal: Estimated PFOS+PFHxS concentration in offal* (µg/kg)	Offal: FSANZ trigger value for offal (µg/kg)	Offal: Hazard Quotient (HQ) (public consumption)**	Milk: Estimated PFOS+PFHxS concentration in milk (µg/kg)	Milk: FSANZ trigger value for milk (µg/kg)	Milk: 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.

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.*

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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