From: Out of scope
Sent: Friday, 15 October 2021 2:34 PM
To: Out of scope
Cc: Out of scope
Subject: RE: Emerging contaminants ambient data
Attachments: EPA 2020 Publication 1879 Emerging Contamiants Summary 19_20.pdf; EPA Pub 1734 PFAS in Waterfowl 2019.pdf; EPA Publication 1924 Emerging contaminants in Mildura 2020.pdf; SupplementaryTables_ExecSummary_2020_04_20.pdf

Hey Out of scope

The 2019-2020 VIC ambient executive summary was published, along with Mildura and ducks in wetlands.
I'll confirm with Minna on Monday if we can share the Supplementary Table (attached) with EPA NSW.

We're writing up these articles for publication:

- PFAS in water, sediment and soil – should be submitted for review soon
- Phthalates submitted as a short article, but the journal wanted lower LORs (which NMI have now developed)
- Pesticides is a fair way off (months)
- Any metal publication is further away (unless you want to take it on? 😉)

There were some conversations within the NEMP working group of sharing data, but not sure what this would look like.
For raw data we'd probably consider a data sharing agreement.

Cheers, Out of scope

Out of scope
Water Sciences
Please note I work Out of scope

Environment Protection Authority Victoria
Centre for Applied Sciences, Macleod
Out of scope
@epa.vic.gov.au | www.epa.vic.gov.au

From: Out of scope @epa.vic.gov.au>
Sent: Friday, 15 October 2021 1:56 PM
To: Out of scope @epa.vic.gov.au>; Out of scope @epa.vic.gov.au>
Cc: Out of scope @epa.vic.gov.au>
Subject: Emerging contaminants ambient data

Hi Out of scope

Out of scope and I recently met with some colleagues from NSW EPA who were interested in seeing the data gathered during the recent ambient sampling program.

Is there plans to make these data available to other regulators/the general public?

Cheers

Out of scope
Advisory Land & Waste Sciences
Centre for Applied Sciences, Macleod
Out of scope
@epa.vic.gov.au | www.epa.vic.gov.au

EPA acknowledges Aboriginal people as the first peoples and Traditional custodians of the land and water on which we live, work and depend. We pay respect to Aboriginal Elders past and present and recognise the continuing connection to, and aspirations for Country.

Emerging contaminants assessment 2019–20: Summary of results

Publication 1879 September 2020

Summary report

EPA analysed samples of soils, water and sediment at 101 sites across Victoria for emerging and legacy contaminants (including PFAS).

The results for all emerging contaminants are consistent with concentrations EPA has observed in previous studies (Sardina et al. 2019; Sharp et al 2020; EPA publication 1870, May 2020). In soil and sediment, PFAS concentrations were mostly below guideline values. In water, concentrations of some PFAS exceeded ecological guideline values. Concentrations of pesticides were mostly below guidelines across all land use types with some exceptions, such as atrazine, simazine, p'p-DDE, DDT and dieldrin. Of the phthalates quantified, only DEHP and BBP were found above the limit of reporting. Metals were found in varying concentrations across all land use types in metropolitan and regional Melbourne.

This study enables EPA to further identify the extent and magnitude of emerging and legacy contaminants across Victoria, to inform where there may be priority areas, regulatory responses, and identify sectors to work with to prevent and reduce environmental pollution.

Definitions and methodology

Selection of sites

EPA selected sites representing five land use types: background, low-intensity agriculture (grazing), high-intensity agriculture (cropping, horticulture), urban residential, and urban industrial.

Background sites represented natural environments with no or minimal human impact. Background in this context does not necessarily mean pristine conditions, but rather conditions where diffuse sources of contamination, such as atmospheric drift, may be possible.

Water, sediment, and soil samples were collected at around 100 sites (97 – 107 depending on the matrix and analyte group) in October-December 2019. In addition, 145 sites were sampled for soil only to establish background conditions for PFAS.

Sampling methodology and laboratory analysis

The methodologies for sample collection, handling, transport, storing, and quality assurance and control were consistent with EPA publication IWRG 701 (2009) and PFAS National Environmental Management Plan (NEMP) (2018). Emerging contaminants were determined using USEPA 8270, USEPA 537 and USEPA-821-R-11-007, Pesticide Analytical Manual (1999), AS4479, USEPA 3050, 200.7, 6010, 200.8 and 6020 methods at the National Measurement Institute. Four groups of emerging contaminants were analysed: phthalate esters (phthalates), per and poly-fluorinated alkyl substances (PFAS), pesticides and total metals. Of 33 PFAS-compounds analysed the three most frequently detected were PFOS, PFHxS and PFOA.

Results

PFAS: PFOS, PFHxS, and PFOA

Concentrations of PFAS compounds in freshwaters, freshwater sediments, and soils samples across five land use types were found to be relatively low. The maximum concentration of PFOS + PFHxS is 0.149 µg/L in water (Table 1). PFOS and PFHxS are summed to benchmark against existing guideline values. Across land uses, PFOS, PFHxS and PFOA concentrations ranged from <0.0002 to 0.081 µg/L in water. In sediments, PFOS, PFHxS and PFOA concentrations were below the limit of reporting and ranged from <0.002 to 0.039 mg/kg across all land use types. In soil, PFOS, PFHxS and PFOA concentrations ranged from <0.001 to 0.029 mg/kg for PFOS and PFHxS across all land use types. Of the 145 soil samples taken to establish background concentrations, most were below the limit of detection (data not shown).

Authorised and published by
Environment Protection Authority Victoria
200 Victoria Street, Carlton VIC 3053
W epa.vic.gov.au | T 1300 372 842 (1300 EPA VIC)

Table 1. Minimum and maximum concentrations across all land use types for PFOS, PFHxS, and PFOA[#].

PFAS	Ambient					
	Water (n = 104)		Sediment (n = 102)		Soil (n = 107)	
	Range (µg/l)	Detected (%)	Range (mg/kg)	Detected (%)	Range (mg/kg)	Detected (%)
PFOS	<0.0002 – 0.081	88	<0.002 – 0.039	25	<0.002 – 0.029	25
PFHxS	<0.0002 – 0.068	86	<0.001 – 0.0011	2	<0.001- 0.0011	1
PFOA	<0.0005 – 0.036	82	<0.001 – 0.0015	1	<0.001	0

[#]The minimum concentration is the LOR for each PFAS compound. Number of ambient sites per land use type: background (16-17), low-intensity agriculture (19), high-intensity agriculture (11), urban residential (24-25), and industrial (31-35).

Pesticides

Concentrations of pesticides were mostly below guidelines across all land use types with some exceptions.

- In water, concentrations of pesticides detected ranged from 0.0074 to 1.42 µg/L across all land use types. For example, herbicide simazine was only detected in water (<0.01 – 1.3 µg/L, maximum concentration exceeds the ecological 99% species protection level), and most frequently in sites with urban industrial and urban residential land uses.
- In sediments, the insecticide bifenthrin, a key ingredient in termiticides for residential housing, was detected in 34% of sites from <1 up to 79 µg/kg. Currently, there are no guideline values for bifenthrin, however, the higher concentrations observed suggest toxicity to aquatic invertebrates. The insecticide DDT was detected from <1 to 200 µg/kg and its metabolite p'p-DDE was detected from <1 to 170 µg/kg, with ~ 50% of the detected concentrations exceeding the sediment quality guidelines. Dieldrin was detected at 26% of sites with concentrations ranging from <1 to 39 µg/kg, with the higher concentrations exceeding the sediment quality guideline value.
- In soils, insecticide p'p-DDE was detected from <1 up to 150 µg/kg, and dieldrin from <1 up to 38 µg/kg, concentrations of which were below human health and ecological guidelines (ASC NEPM, 2013) across all land use types.

Phthalates

Of six phthalates quantified, two phthalates were detected above the limit of reporting, but none exceeded the drinking water guideline values. Bis(2-ethylhexyl) phthalate (DEHP) was found in 26 sediment sites at concentrations ranging from 0.49 to 15 mg/kg (across different land use types), in 11 soil samples from 0.38 to 2.9 mg/kg (across different land use types) and in one water sample at concentration of 0.0064 mg/L (urban residential). Benzyl phthalate (BBP) was detected above limit of reporting (<1 mg/kg) in sediments at three different sites (1.2 mg/kg) located in metropolitan Melbourne.

Metals

Total metals (22 out of 23 sampled) were found across all land use types in metropolitan and regional Victoria, including those typically associated with toxicity (Ni, Zn, Cu, As, Cr, Pb, Cd, Hg in decreasing order of detection).

- In water, total metal concentrations frequently exceeded the ecological 95% species protection guidelines for Cu (60% of sites), Zn (38%) and Cr (30%), with concentrations ranging <1 to 7.2 µg/L for Cu, <1 to 130 µg/L for Zn and <1 to 13 µg/L for Cr. Further, detected concentrations exceeded the ecological 95% species protection guidelines only in a small number (2-5%) of sites for As, Cd, Pb and Ni.
- In sediments, concentrations exceeded sediment guidelines for Ni (57% of sites), for Zn (26%), with concentrations ranging from 2.5 to 160 mg/kg for Ni and from 6.9 to 1,420 mg/kg for Zn. In addition, concentrations exceeded the guidelines for As and Pb (13% of sites), for Cu (10%), for Hg (7%) and for Cr (5%).
- In soils, concentrations only exceeded ecological and human health guidelines for arsenic in 5% of sites, ranging from <0.5 to 380 mg/kg.

Limitations of the study

- Further spatial and temporal replication would provide a greater understanding of and confidence in the variation of concentrations of contaminants in the environment.
- Environmental samples (water, sediment, soil) should be combined with biota (fish, macroinvertebrate) samples to gain a better understanding of the ecosystem level impacts of emerging contaminants.

PFAS in Victorian waterfowl

Investigation of the presence of PFAS in 19 wetlands in Victoria

Publication 1734 March 2019

Technical report

Executive summary

Investigating PFAS in the environment

Per- and Polyfluorinated alkyl substances (PFAS) are a group of manufactured chemicals that have been used for several decades in aqueous film-forming foams (AFFF) and other industrial and consumer products such as waterproof clothing, carpets and cookware. The presence of PFAS in the environment and their accumulation in wildlife has been reported worldwide. Concerns about PFAS contamination prompted Environment Protection Authority Victoria (EPA) to conduct a statewide assessment in 2018 into the nature and magnitude of PFAS concentrations in the environment and waterfowl to better understand the potential for ecological and human health impacts. Four common waterfowl species (Pacific Black and Pink-eared Duck and Chestnut and Grey Teal) were specifically targeted for the assessment because they are widely dispersed throughout Victorian wetlands.

In February 2018, EPA assessed waterfowl from three wetlands to better understand the extent and distribution of PFAS contamination ahead of the duck hunting season. PFAS was detected in waterfowl from all three wetlands, with concentrations exceeding trigger points for investigation in Heart Morass wetland, East Sale. As a result, EPA maintained its previous precautionary health advice (EPA publication 1672.2, 2 August 2018) to avoid the consumption of waterfowl from Heart Morass, and extended that advice to Dowd Morass, due to its proximity to a PFAS-contaminated site.

In May and June 2018, EPA conducted a more extensive study into PFAS concentrations in waterfowl from 19 wetlands around the state. This study aimed to identify potential risks associated with the consumption of waterfowl from popular recreational duck hunting sites. A human health risk assessment was conducted, based on PFAS concentrations in 41 composite samples from a total of 166 waterfowl specimens.

PFAS levels detected in soil, sediment, water and waterfowl

Variable concentrations of PFAS compounds were detected in waters, sediments and/or soils at nine of the 19 wetlands tested in May and June 2018.All others were below the analytical limits of reporting.

All **sediment** and **soil** concentrations detected were below the ecological guidelines and human health-based investigation levels for soil.

All concentrations in **water** were below the ecosystem 99% species protection levels, except for four wetlands and one marine site close to Jones Bay in Gippsland Lakes. These guidelines are based on the general potential for bioaccumulation in aquatic biota but were not derived specifically for bioaccumulation in waterfowl. PFAS concentrations at Reedy Lake on the Bellarine Peninsula exceeded drinking water standards.

Waterfowl tissue samples were found to contain variable PFAS concentrations. Perfluorooctane sulfonate (PFOS) and perfluorohexane sulphonic acid (PFHxS) concentrations in waterfowl from nine wetlands exceeded Food Standards Australia and New Zealand (FSANZ) trigger points for investigation. As a result, health risk assessments were undertaken on the samples that exceeded FSANZ trigger points for investigation, and health advisories issued.

Health advisories issued for consumption of waterfowl

EPA recommends restricting the consumption of recreationally-hunted waterfowl for the following wetlands:

- **Macleod Morass (Bairnsdale):** children should limit their consumption of waterfowl breast meat to one serve (one serve = 75g for children) per month and adults and children should not eat liver. Concentrations of PFAS in Macleod Morass did not exceed human health guidelines for recreation in waters, soils and sediments.

Authorised and published by Environment Protection Authority Victoria
200 Victoria Street, Carlton VIC 3053
W epa.vic.gov.au | **T** 1300 372 842 (1300 EPA VIC)

- **Hospital Swamp (Bellarine Peninsula):** children should limit their consumption of waterfowl breast meat to one serve (one serve = 75g for children) per month and adults and children should not eat liver. Concentrations of PFAS in Hospital Swamp did not exceed human health guidelines in waters, soils or sediments.
- **Heart Morass** and **Dowd Morass wetlands (East Sale):** waterfowl should not be eaten, consistent with previous advice (EPA publication 1672.2, 2018).

EPA also recommend that people should exercise caution when consuming waterfowl hunted from wetlands that are close to those with current health advisories as waterfowl can freely move between wetlands. Given the proximity of Reedy Lake to Hospital Swamp, unless further evidence suggests otherwise, waterfowl harvested from Reedy Lake may be the same of those inhabiting Hospital Swamp.

Further investigation

EPA will conduct further work to better understand the characteristics and extent of PFAS concentrations in Victoria's wetlands and waterfowl. This will include the re-analysis of PFAS in individual specimens of Pacific Black Duck collected from Hospital Swamp, and further sampling for PFAS in sediments and waters to identify potential sources around Hospital Swamp, Reedy Lake and Macleod Morass. EPA will continue to review risks from PFAS and other emerging contaminants and investigate better ways to manage and communicate these risks to protect the environment and people from harm.

Table of contents

List of figures

List of tables

Background

Key information regarding PFAS in the environment

- Per- and polyfluorinated alkyl substances (PFAS) are a large group of manufactured chemicals widely used for decades in aqueous film-forming foams (AFFF) and many industrial and consumer products such as waterproof clothing, new carpets, food packaging and non-stick cookware.
- PFAS are of concern as they can persist for decades in the environment and accumulate in animals and people. Most people have background levels of PFAS in their bodies.
- Waterfowl accumulate PFAS in their bodies through from continual consumption of contaminated food, water and sediment.
- At sites where AFFF was used for fire suppression (mostly for training and to control fires involving flammable liquids such as fuel and oil), PFAS can migrate into the environment and waterways.
- Investigations of relationships between PFAS exposure and health effects in humans have not shown consistent findings. Evidence of relationships between highly exposed occupational populations and health effects have also been inconsistent. Experimental studies on laboratory animals indicate possible effects on the immune system, liver, reproduction and development. However, PFAS behave differently in smaller animals compared with humans. Therefore, results from laboratory experiments may not reflect potential health impacts in humans.
- As a precaution, Environment Protection Authority Victoria (EPA) recommends minimising human exposure to PFAS wherever possible.
- An Interagency Working Group on Emerging Contaminants in Biota was established to build on the 2018 screening assessment of PFAS contamination in waterfowl to inform a greater understanding of the extent of emerging contaminants, including PFAS, in waterfowl and recreationally caught fish and in the environment (water, soils and sediment) in Victoria. The Interagency members include EPA; Parks Victoria; Department of Environment, Land, Water and Planning's Arthur Rylah Institute for Environmental Research (ARI); Game Management Authority; the Department of Jobs, Precincts and Regions and Agriculture Victoria; the Victorian Fisheries Authority; and the Department of Health and Human Services.
- Further information can be found in EPA's *Interim position statement on PFAS* (EPA publication 1669.2, 2018): https://www.epa.vic.gov.au/our-work/publications/publication/2018/august/1669-2).
- Further background information on PFAS and health is available from:
  - Victorian Department of Health and Human Services' (DHHS): https://www2.health.vic.gov.au/public-health/environmental-health/per-and-poly-fluoroalkyl-substances-pfas,
  - Australian Department of Health: http://www.health.gov.au/pfas,
  - Expert Health Panel (enHealth) for Per- and Poly-Fluoroalkyl Substances (PFAS), Report to the Minister, March 2018 http://www.health.gov.au/internet/main/publishing.nsf/Content/ohp-pfas-expert-panel.htm
- Further information on PFAS and agriculture is available from Agriculture Victoria: http://agriculture.vic.gov.au/agriculture/animal-health-and-welfare/animal-health/faqs-pfas-in-livestock

Previous assessment of PFAS in waterfowl

The Department of Defence (DoD) identified Heart Morass and Dowd Morass, near East Sale, Gippsland as PFAS-contaminated sites due to AFFF used in fire-fighting training (EPA publication 1672.2, 2018). Subsequent investigations revealed PFAS concentrations in waterfowl exceeded thresholds for human consumption (DoD 2017). As an extension of this work, EPA conducted its own sampling and analysis of PFAS in waterfowl at three wetlands in February 2018: Heart Morass in East Sale; Lake Bolac, south of Ararat; and Hird Swamp, south west of Cohuna. The purpose of this sampling program was to see whether wetlands with no known PFAS sources would also show waterfowl with elevated PFAS concentrations (EPA publication 1669.2). PFAS was detected in waterfowl from all three locations, with elevated concentrations found only at Heart Morass. With the support of the Chief Health Officer, Department of Health and Human Services Victoria, EPA maintained its previous public health advice to avoid the consumption of waterfowl from Heart Morass and extended that advice to include Dowd Morass, due to its proximity to a PFAS-contaminated site. Waterfowl were further investigated due to previous known contamination issues from Heart Morass and because they are widely dispersed throughout Victoria and are not confined to a specific wetland.

Study aims

To improve understanding of PFAS contamination in waterfowl across the state, EPA conducted an additional PFAS sampling program in May and June 2018. This was a broader spatial study of PFAS concentrations in waterfowl from recreational wetlands across Victoria. The aims of this study were to:

1) identify potential environmental and human health risks from concentrations of PFAS in waterfowl, targeting the most popular wetlands used for hunting.
2) compare PFAS concentrations from water, sediment and soil samples with relevant guidelines and with concentrations in waterfowl.

Methods

Identification of sampling sites and species of waterfowl to be collected

EPA engaged the Arthur Rylah Institute for Environmental Research (ARI) to design the sampling program and ensure that the project gained ethics approval. Annual surveys of duck hunter success rates were used to identify the most popular wetlands for waterfowl hunting. These sites were targeted for sampling, along with wetlands close to areas previously sampled by EPA and DoD where PFAS concentrations in waterfowl had exceeded trigger points for investigation (ARI, 2018).

Analysis of PFAS concentrations in waterfowl from 2017 and February 2018 by EPA indicated that approximately six waterfowl should be collected for each species in each wetland for clear results. Consequently, the sampling plan targeted collection of six waterfowl specimens from each species.

In the 2017 hunting season, four species made up 75% of the total number of waterfowl harvested (Table 1). These four common game species were therefore chosen for sampling: Pacific Black Duck, Grey Teal, Chestnut Teal and Pink-eared Duck. However, the actual species and number of waterfowl specimens collected in May and June 2018 depended on the population of species in wetlands at the time of collection.

EPA and ARI partnered with licensed hunters Field and Game (Australia) (F&G), who harvested and delivered the waterfowl to ARI staff in the field for processing. In many wetlands, fewer than the target of six specimens per species were collected. Assessments using fewer waterfowl were made, therefore with reduced confidence in the conclusions.

Table 1 –Total harvest of waterfowl based on 200 licence holders for 2017 and estimated percentage based on 2017 surveys of game hunting as well as species ecology.

Category	Reported harvest[1]	Percentage of harvest[1]	Habitat[2,3]	Movement behaviours[2,3]	Feeding and diet[3]
Chestnut Teal, *Anas castanea*	108	3%	Coastal salt- and fresh-water and wetlands	Sedentary and vagrant	Dabbling on plants and invertebrates
Grey Teal, *Anas gracilis*	1,386	40%	Freshwater and saltwater wetlands	Opportunistic and nomadic	Dabbling on plants and invertebrates
Pacific Black Duck, *Anas superciliosa*	938	27%	Wetlands, ponds, sheltered estuaries and coastal waters	Sedentary; dispersive and nomadic	Dabbling on plants and invertebrates
Pink-eared Duck, *Malacorhynchus membranaceus*	159	5%	Shallow waters: lakes, swamps and wetlands.	Nomadic	Filtering small plants, algae and invertebrates

References: 1) Game Management Authority 2017; 2) Menkhorst et al 2017; 3) Museums Victoria 2018.

Notes: Typology of movement behaviours from Newton 2008: Sedentary - Remaining year-round in the same limited area, showing no direction bias in movements and generally over short distances (non-migratory).; Vagrant – An individual bird that appears outside its regular range and off their usual migration route.; Opportunistic – the ability to breed at any time of year, whenever food is sufficiently plentiful, unconstrained by season.; Nomadic – Species that have no fixed spatial or temporal pattern of migration, and no fixed directional preferences, leading to irregular changes in distribution.; and, Dispersive – Species that move with no fixed direction or distance from their breeding site.

Location of wetlands for testing

Waterfowl, sediment, soil and surface water samples were collected from 19 wetlands across Victoria (Figure 1). Licensed F&G members harvested four common, recreationally-hunted waterfowl species during the duck hunting season in May and June 2018.

EPA and ARI collected environmental samples (single surface water, soil and sediment samples) in May and June 2018 at most wetlands, with two exceptions: Newlands Lake in Aspley due to the extensive distance, associated additional costs, and low-likelihood of contamination; and Heart Morass, as DoD had already done extensive sampling there in 2017. Additional opportunistic samples were collected during routine EPA monitoring in Lake Wellington and Lake King North (near to Jones Bay).

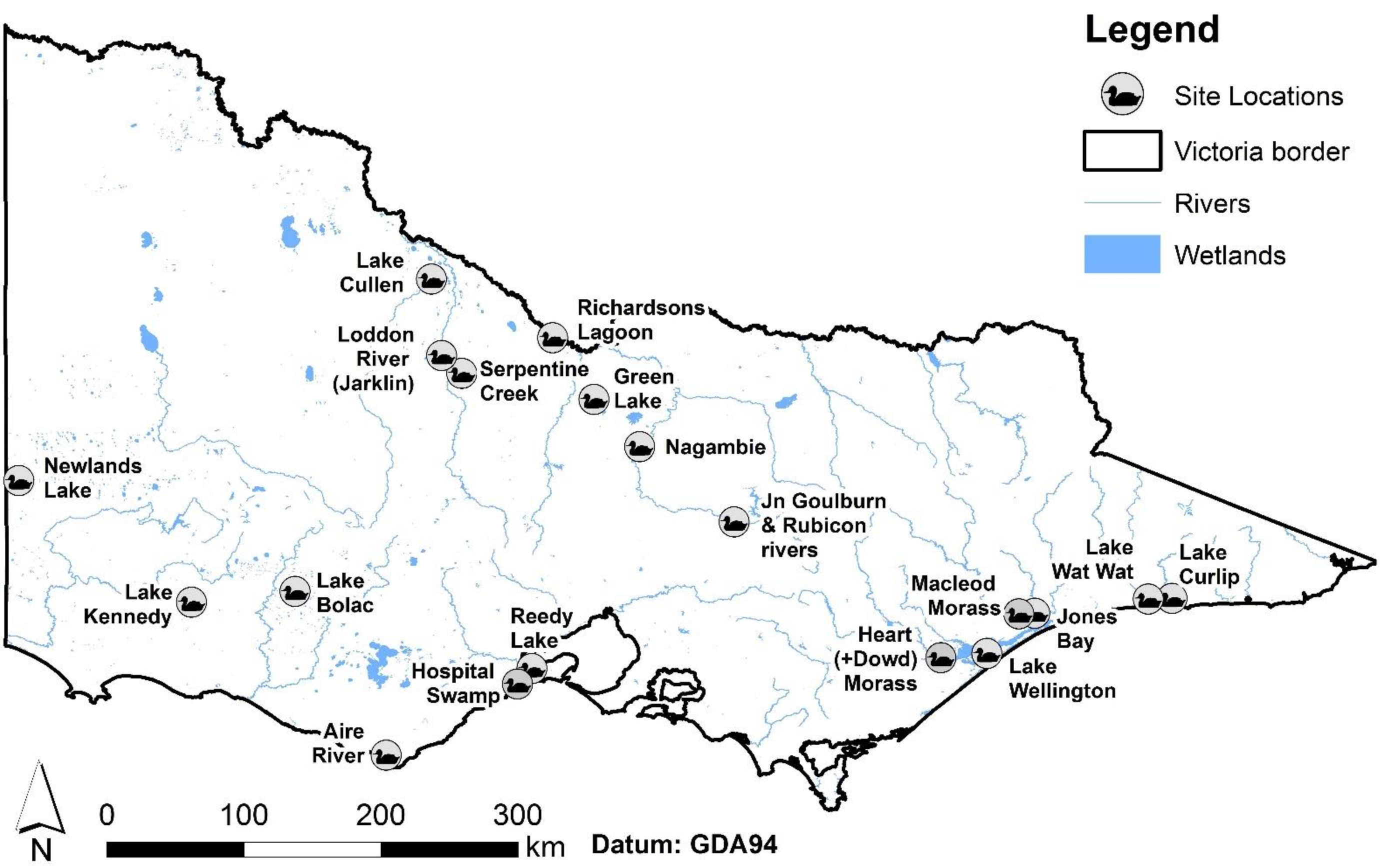


Figure 1 – Wetland sampling sites where waterfowl and environmental samples were collected across Victoria, May to June 2018.

Sample preparation and chemical analysis

Samples for waterfowl and environmental samples were stored on ice and accompanied by chain of custody documentation on transit from the field to the laboratory. For waterfowl, ARI dissected breast meat and liver from each specimen in their laboratory and stored these frozen in glass jars following handling protocols provided by the National Measurement Institute (NMI).

A staged approach was adopted for the analysis of the breast and livers. Given that PFAS contamination was not known or expected at most of the sites, composite samples (combined from individual waterfowl) within a species at each wetland were analysed. Composite sampling allowed for more wetlands and species to be analysed by combining multiple individual waterfowl specimens, reducing the overall number of samples requiring analysis by providing an average PFAS concentration for each species (FSANZ 2009). Where there was known contamination, or if the results of composite testing were close to or exceeded trigger points for investigation, then the individual specimens making up the composite sample were re-tested individually to better understand variation in PFAS concentrations. This data was used in the health risk assessment (FSANZ 2009). Using this approach, 11 individual ducks were analysed from Heart Morass (six) and Macleod Morass (five), while composite samples were used in all other wetlands.

Chemical analysis was conducted by NMI on all waterfowl breast and liver samples, as well as the water, sediment and soil samples. Thirteen common PFAS compounds were analysed in all sample types, including perfluoroalkyl sulfonic acids (such as PFOS and PFHxS) and perfluoroalkyl carboxylic acids (such as PFOA). The list of PFAS compounds, analytical limits of reporting (LORs) and methods used by NMI are reported online (2018a), with one exception that perfluorobutyrate (PFBA) was not analysed in waterfowl.

Data analysis

Concentrations below the limit of reporting (LOR) were assigned half the LOR for subsequent analyses as a conservative measure (enHealth 2012; FSANZ 2017). Waterfowl samples in the survey analysed as composites of multiple specimens provided average concentrations for each compound in each species (FSANZ 2017). For environmental decisions based on small sample sizes (<10), the use of a non-parametric approach based on intervals (median, 50th percentile) is appropriate (Goudey 2007). Presenting the concentration range and the median is typically used for dietary modelling where analytical data for individual samples are available (FSANZ 2017).

Screening of results against guidelines

The PFAS National Environment Management Plan (NEMP) developed by the Heads of EPAs Australia and New Zealand (HEPA 2018) establishes guideline concentrations for environmental sample types for public health and ecological investigations. PFOS or PFOA concentrations exceeding these guidelines indicate the need for further investigation. As there are no consumption guidelines for waterfowl, sample concentrations were compared against Food Standards Australian and New Zealand (FSANZ, 2017) trigger points for investigation in mammalian meat (breast) and mammalian offal (liver). Water samples were compared against guideline values for ecological protection and health-based guideline values for recreational and drinking water. Soil and sediment concentrations were compared against Health Investigation Levels (HILs), which aim to protect human health and indicate the need for further detailed risk assessment (Table 2).

As PFOS and PFOA bioaccumulate in wildlife, the national guidelines recommend using the 99% protection standard for species protection for ‘slightly to moderately disturbed systems’ (EPA publication 1633.2, 2017). As Australian laboratory analyses can only reliably detect higher concentrations of PFOS around 0.001 µg/L, EPA adopted the current LORs as the practical standards for ‘slightly to moderately disturbed’ and ‘high conservation value systems’, while the 95% protection standard will apply for highly disturbed systems (Warne et al., 2015).

Table 2: Guideline values for environmental samples and trigger points for investigation for waterfowl and their sources.

Guidelines	Reference	PFOS	PFOS + PFHxS	PFOA
Drinking water	Australian Government Department of Health, 2017	-	0.07 ug/L	0.56 ug/L
Recreational water	Australian Government Department of Health, 2017	-	0.7 ug/L	5.6 ug/L
Environmental – 99% species protection level	EPA 2017, publication 1633.2	0.00023 ug/L	-	19 ug/L
Environmental – 95% species protection level	EPA 2017, publication 1633.2	0.13 ug/L	-	220 ug/L
Sediment and soil – public open space	EPA 2017, publication 1633.2 Based on 20% of FSANZ TDI, and National Environment Protection (Assessment of Site Contamination) Measure) (1999), Health Investigation Level C (HILs), Public Open Space	1 mg/kg	1 mg/kg	10mg/kg
Interim soil – ecological indirect exposure	EPA 2017, publication 1633.2 Based on Canadian Federal Environment Quality Guidelines (2017)	0.01 mg/kg	-	-
Food consumption – mammalian meat	Food Standards Australia New Zealand (FSANZ, 2017)	3.5 µg/kg	3.5 µg/kg	28 µg/kg
Food consumption – mammalian offal	Food Standards Australia New Zealand (FSANZ, 2017)	96 µg/kg	96 µg/kg	765 µg/kg
Tolerable Daily Intake (TDI)	Food Standards Australia New Zealand (FSANZ)	0.02 µg/kg bw/day	0.02 µg/kg bw/day	0.16 µg/kg bw/day

Note: bw=body weight, µg = micrograms (1 µg = 0.001 mg)

Human health risk assessment for consumption of waterfowl

FSANZ trigger points for investigation

Where PFAS concentrations in waterfowl exceeded the FSANZ trigger points for investigation, a human health risk assessment was completed to identify any potential risks associated with the consumption of waterfowl.

Waterfowl consumption scenarios

In 2017, the estimated upper range of individual waterfowl taken during the hunting season was 20.8 individuals per hunter (95th percentile) (Game Management Authority, 2017). This risk assessment used this upper range of harvested numbers (21 waterfowl per year) as a conservative estimate of consumption rates of waterfowl breast and liver by recreational hunters. The consumption scenario for waterfowl breast was one serve per week (based on 150 g for adult and 75 g for child). The consumption scenario for liver was 10 g per week (for adults and children) (enHealth, 2012).

Tolerable daily intake

The tolerable daily intake (TDI) is a level of intake for PFOS + PFHxS that is considered safe over a lifetime based on the findings of toxicological studies in laboratory animals. The consumption scenarios were used as the basis to derive tissue concentrations of PFOS + PFHxS in duck breast and liver that would result in a consumer reaching the TDI for PFOS + PFHxS of 0.02 µg/kg body weight / day (FSANZ 2017). The concentrations of PFOA were all wellbelow the listed trigger points for investigation and therefore this compound was not included in the risk assessment.

Consumption thresholds

The concentration of PFOS + PFHxS in waterfowl breast for the consumption scenario of one serve per week was calculated as 36 µg/kg for children and 74 µg/kg for adults. The concentration of PFOS + PFHxS in liver for the consumption scenario of one serve per week was calculated as 268 µg/kg for children and 1,100 µg/kg for adults. These consumption thresholds should not be exceeded for adults and children. Thresholds were compared with tissue concentrations for composite samples (from all wetlands) and individual samples from Heart Morass and Macleod Morass to determine EPA's advice.

Results and discussion

PFAS in environmental samples

A summary of the environmental concentrations for PFAS in wetlands is shown below in Table 3, with only detected concentrations shown. All sediment and soil concentrations were below the ecological guidelines and human health investigation levels for soil (NEPM 2018). Concentrations of PFAS in sediment samples from all 19 wetlands were considerably lower than the Health Investigation Levels (HILs), indicating low risks to human health. Sites where no PFAS were detected in environmental samples included Greens Lake, Serpentine Creek, Jones Bay, Aire River, Lake Nagambie, Lake Kennedy, Junction of Goulburn and Rubicon rivers, Lake Wat Wat, and Lake Bolac. While no PFAS concentrations were detected in Jones Bay, PFOS + PFHxS was detected in waters nearby in Lake King North, Gippsland Lakes (Table 3).

PFAS concentrations in the surface waters of all but one of the 19 wetlands were below the drinking water quality guideline value (0.07 µg/L), and all sites were below the recreational water quality guideline value (0.7 µg/L). Water concentrations in Reedy Lake exceeded the drinking water guidelines for PFOS + PFHxS (>0.07 ug/L) (Table 3). This could pose potential risks if these waters are used for drinking by wildlife and other animals, as PFAS can accumulate and persist in the tissues of higher animals. PFAS concentrations in Reedy lake did not exceed the recreational guidelines (<0.7 ug/L), indicating that waters are suitable for recreational uses such as kayaking.

Although no concentrations of PFAS were identified in environmental samples at Lake Curlip, waterfowl tissues collected at this site exceeded trigger points for investigation. This could either be a result of waterfowl moving from another area with higher concentrations of PFAS; or the single sediment, water and soil samples may not have fully characterised environmental concentrations of PFAS at the site.

Environmental samples from all wetlands in this study (excluding Heart Morass) had concentrations of PFOS and PFOA below ecosystem guideline values for highly modified ecosystems (95% species protection). However, ecological water quality guidelines for PFOS are set at levels designed to protect multiple species and prevent bioaccumulation across multiple trophic levels (Australian Government 2016). Any detection of PFOS concentrations in waters is deemed to exceed 99% protection levels for bioaccumulation, as there is the risk of uptake by aquatic biota. Guidelines do not include protection for air breathing animals which inhabit or prey on aquatic ecosystems and may not account for effects from bioaccumulation of toxicants (Australian Government 2016). Previous PFAS measurements in Heart Morass by the DoD in October to December 2016 showed elevated concentrations in sediments, waters and waterfowl close to the outlet from the RAAF Base East Sale. To specifically assess greater risks and uptake of PFAS on the environment including in waterfowl, a human health and ecological risk assessment was completed as part of the site assessment for Heart Morass (DoD 2017), involving measurement of PFAS concentrations in waterfowl food sources.

Table 3 - Summary of environmental concentrations of PFAS detected in wetlands and guidelines for water (recreational, ecosystem guidelines 95% protection level and drinking water), sediment and soil (human health standards), and Waterfowl (yes/no exceeding FSANZ).

Guidelines		Sediment			Soil	Waters				Water-fowl
		PFOS + PFHxS	PFOA	PFOS	PFOS	PFHxS	PFOA	PFOS	PFOS + PFHxS	PFOS + PFHxS
Units		mg/kg	mg/kg	mg/kg	mg/kg	µg/L	µg/L	µg/L	µg/L	Exceeding Trigger points for investigation [d]
LORs		0.003	0.001	0.002	0.0003	0.001	0.001	0.002	0.003	
Drinking water standard [a]		-	-	-	-	0.07	0.56	0.07	0.07	
Recreational water quality [b]						0.7	5.6	0.7	0.7	
NEPM HILs [c]		1	10	1	1	-	-	-	-	
Interim soil – ecological [c]					0.01					
Ecological 99% protection [c]							19	0.00023		
Ecological 95% protection [c]		-	-	0.14	0.14	-	220	0.13	-	
Area	**Wetland name**	**Sediment**			**Soil**	**Waters**				**Water-fowl**
Sale	*Heart Morass† Min-Max (Median); n=30(water), n=32(sed)*	<0.0004-1.93 (0.0574)	<0.0002-0.0291 (0.0007)	<0.0002-*1.66* (0.0504)	N/A	<0.002-0.31 (0.16)	<0.002-0.009 (0.004)	*0.004-0.494 (0.124)*	0.004-**0.74** (0.29)	Y
Sale	Lake Wellington‡ (min-max) *n*=3(sed/water); *n*=2 (soil)	0.003	<LOR	0.003	<LOR	0.0011-0.043	<0.003-0.0012	*0.003-0.004*	0.0043-0.0472	Y
Kerang	Lake Cullen	<LOR	<LOR	<LOR	<LOR	0.0011	<LOR	<LOR	0.0013	N
Geelong	Reedy Lake	<LOR	<LOR	<LOR	0.006	0.028	<LOR	<LOR	**0.082**	Y
Geelong	Hospital Swamp	0.019	<LOR	0.016	0.0042	<LOR	<LOR	<LOR	<LOR	<LOR
Boort	Loddon River	<LOR	<LOR	<LOR	<LOR	<LOR	<LOR	*0.011*	0.0152	N
Bairnsdale	Jones Bay	<LOR	<LOR	<LOR	<LOR	<LOR	<LOR	<LOR	<LOR	N
Gippsland Lakes§	Lake King North§	<LOR	<LOR	<LOR	-	0.0099	<LOR	*0.018*	0.0279	-
Bairnsdale	Macleod Morass	<LOR	<LOR	<LOR	<LOR	<LOR	0.015	*0.016*	0.030	Y
Echuca	Richardsons Lagoon	<LOR	<LOR	<LOR	<LOR	<LOR	0.001	<LOR	<LOR	Y
Marlo	Lake Curlip	<LOR	<LOR	<LOR	<LOR	<LOR	<LOR	<LOR	<LOR	Y
Apsley	Newlands Lake	-	-	-	-	-	-	-	-	N

Notes: <LOR = not detected; - Not sampled; Wetlands were excluded if no environmental concentrations of PFOS, PFHxS or PFOA were detected. No concentrations detected above LORs at: Greens Lake, Serpentine Creek, Aire River, Lake Nagambie, Lake Kennedy, Jn Goulburn & Rubicon rivers, Lake Wat Wat and Lake Bolac (data not shown).
Concentrations in **bold** exceed guideline values. Units are mg/kg (dry weight) for sediment and soil, and µg/L for waters. Unless stated otherwise, single samples were collected for sediment, soil and water. Concentrations highlighted exceed HIL (soil/sediment) or Recreational guidelines (water); **Bold** Exceeds Drinking Water; *Italics* exceed ecological 95% protection.

†Data Source: Department of Defence (2017), PFAS Investigation, Heart Morass surface water and sediment results, Oct-Dec 2016;
‡Three samples for water and sediments from 2 locations, 1 from EPA fixed site, 2 from shoreline; soil samples = 2;
§ EPA (2018) Monitoring the environment: EPA's fixed marine monitoring sites (Gippsland Lakes, additional sampling site)
Guidelines: a, b Australian Government Department of Health, 2017; c EPA 2017 publication 1633.2; d FSANZ 2017

PFAS in waterfowl

A summary of concentrations of 13 PFAS measured in waterfowl are shown in Table 4. PFOS was the most frequently detected compound and also had the highest overall concentrations, with 33 µg/kg in breast and 340 µg/kg in liver for Pacific Black Duck at Macleod Morass (Table 4). The second and third most frequently detected compounds in both liver and breast were PFNA and PFDA, while PFDA also had the second highest maximum concentration in both tissues (Table 4). PFHxS was the fourth most frequently detected compound and had the next highest concentration.

PFOA was detected relatively infrequently in breast samples (5%) compared with liver samples (29%). The maximum concentrations of PFOA from waterfowl across all wetlands were 1.2 and 4.5 µg/kg in Grey Teal breast and liver, respectively, from Macleod Morass. Eleven out of the 13 PFAS compounds analysed were above LORs in liver from one or more waterfowl (Table 3). Both PFHxA (perfluoro hexanoic acid) and PFHpA (perfluoro heptanoic acid) were below the LORs (<0.5 µg/kg) for all samples in liver and breast.

Table 4 – Summary data on the occurrence (detection frequency) of PFAS compounds and concentrations in waterfowl across the 19 wetlands, May – June 2018.

Category		Breast			Liver		
PFAS type	LOR (µg/kg)	Detection Frequency	Median (µg/kg)	Max (µg/kg)	Detection Frequency	Median (µg/kg)	Max (µg/kg)
PFPeA	<0.5	0%	<0.5	<0.5	2%	<0.5	2.9
PFHxA	<0.5	0%	<0.5	<0.5	0%	<0.5	<0.5
PFHpA	<0.5	0%	<0.5	<0.5	0%	<0.5	<0.5
PFOA	<0.3	5%	<0.3	1.2	29%	<0.3	4.5
PFNA	<0.5	15%	<0.5	1.1	49%	<0.5	13
PFDA	<0.5	15%	<0.5	2.3	41%	<0.5	27
PFUnDA	<0.5	5%	<0.5	1.6	15%	<0.5	6.6
PFDoDA	<0.5	12%	<0.5	1.2	20%	<0.5	4.8
PFBS	<0.5	0%	<0.5	<0.5	2%	<0.5	1.3
PFHxS	<0.5	20%	<0.5	2.1	39%	0.5	7
PFOS	<0.3	68%	0.9	33	95%	9.5	340
6:2 FTS	<0.5	0%	<0.5	<0.5	2%	<0.5	1.3
8:2 FTS	<0.5	2%	<0.5	1	2%	<0.5	2.9
PFOS + PFHxS	<0.4[†]	68%	1.15	34.2	98%	10	350

Notes: Median and maximum concentrations for each compound; Units: µg/kg wet weight. Number of composite samples (*n*) = 41. PFPeA (Perfluoro pentanoic acid); PFHxA (Perfluoro hexanoic acid); PFHpA (Perfluoro heptanoic acid); PFOA (Perfluoro octanoic acid); PFNA (Perfluoro nonanoic acid); PFDA (Perfluoro decanoic acid); PFUnDA (Perfluoro undecanoic acid); PFDoDA (Perfluoro dodecanoic acid); PFBS (Perfluoro butane sulfonic acid); PFHxS (Perfluoro hexane sulfonic acid); PFOS (Perfluoro octane sulfonic acid); 6:2 FTS (C2H4-perfluorooctane sulfonate); 8:2 FTS (C2H4-perfluorodecane sulfonate); †PFOS + PFHxS (Σhalf LORs)

Of the 13 PFAS compounds, only three have published guideline values for investigation (PFOS, PFHxS and PFOA). Across Victoria, PFOA was below the LOR in waterfowl sampled from 13 of the 19 wetlands, and concentrations were considerably lower than FSANZ (2017) trigger points for investigation in breast and liver at all sites (Table 4 and Table 5). PFOS + PFHxS concentrations in waterfowl were above the LOR in almost all wetlands (Table 5). Of the 19 wetlands sampled, nine had waterfowl with PFOS + PFHxS concentrations exceeding trigger points for investigation (Table 5).

Table 5 – Summary of waterfowl species harvested from wetlands and the number of wetlands where PFAS concentrations in waterfowl in composite samples exceeded trigger points for investigation, May - June 2018.

Category	Any waterfowl	Chestnut Teal	Grey Teal	Pacific Black Duck	Pink-eared Duck
Number of wetlands	19	9	13	14	5
Number of wetlands where PFOS + PFHxS† were detected	18	9	11	14	5
Number of wetlands where PFOS + PFHxS† trigger point for investigation‡ exceeded	9	3	3	5	2
Number of wetlands where PFOA was detected	6	3	3	2	4
Number of wetlands where PFOA trigger point for investigation‡ exceeded	0	0	0	0	0

Notes: †PFOS and PFOS+PFHxS – same number of exceedances. Half limit of reporting used when PFHxS was not detected. Detections and exceedances shown for breast and/or liver samples. ‡FSANZ (2017)

Concentrations of PFOS and PFOS + PFHxS were below trigger points for investigation in waterfowl from 12 of the 19 wetlands. These wetlands are shown below in Table 6 with no shading. As there was no evidence of PFAS contamination in waterfowl at these locations, no further advice or investigation is required at the time of publishing.

Concentrations of PFOS + PFHxS were close to or above trigger points for investigation in one or more species of waterfowl from several sites in the Gippsland Lakes region near the towns of Sale, Bairnsdale and Marlo, the south-west region in Geelong, and near Echuca in the north of the state (Table 6).

Table 6 – Summary of exceedances of trigger points for investigation in waterfowl, the number of specimens per species for composite samples and the range of PFOS + PFHxS concentrations in breast and liver.

Area	Wetland name	Waterfowl numbers					PFOS + PFHxS (µg/kg)	
		Chestnut Teal	Grey Teal	Pacific Black Duck	Pink-eared Duck	Total Specimens	Breast	Liver
Sale	Heart Morass			6		6	**11.4**	**131**
Sale	Lake Wellington	8	8	2		18	2.8 – **4.8**	14 – 20.9
Kerang	Lake Cullen	7	8	3	4	22	0.7 – 1.7	9.6 – 26.3
Geelong	Reedy Lake	2			1	3	1.8 - **12**	16.3 - 87
Geelong	Hospital Swamp			6		6	**16.3**	**182**
Shepparton	Greens Lake			6		6	0.8	4.0
Boort	Serpentine Creek		4			4	<0.4	1.3
Boort	Loddon River, Jarklin			5		5	<0.4	8.6
Bairnsdale	Jones Bay	4	4	2		10	1.3 - 2.3	26 - 34
Bairnsdale	Macleod Morass	3	3	3	2	11	9.6 - **34**	64 - **347**
Colac	Aire River	4	5	5		14	<0.4 - 0.7	0.9 - 5.7
Echuca	Richardsons Lagoon†		2*	1*		3	**5.4**	55
Nagambie	Lake Nagambie		1	5		6	1.1 - **6.8**	6.5 - 58
Penshurst	Lake Kennedy		6			6	<0.4	<0.4
Mansfield	Jn Goulburn & Rubicon rivers		2	1		3	0.7 - **11.3**	3.5 - 9.8
Marlo	Lake Curlip	3	4	3	2	12	1.2 - **8.7**	2.0 - 57
Marlo	Lake Wat Wat	9	3			12	<0.4 - 0.8	1.5 – 4.5
Lake Bolac	Lake Bolac	2	7	4		13	<0.4	0.8 – 4.6
Apsley	Newlands Lake				6	6	<0.4	2.3

Notes: †analysed as a single combined species composite of Grey Teal and Pacific Black Duck
Shading indicates PFOS + PFHxS concentrations in waterfowl exceeded trigger points for investigation in one or more species (grey), breast only (light yellow) and both breast and liver (orange). PFOS + PFHxS concentration range (min – max) for composite samples across species are shown with exceedances in bold. ‡Trigger points for investigation (FSANZ, 2017) for PFOS + PFHxS 3.5 µg/kg (breast) and 96 µg/kg (liver).

Relationships between environmental and waterfowl PFAS concentrations

There are several environmental factors which could be influencing PFAS concentrations in waterfowl. It is expected that the most likely factors causing PFAS contamination in waterfowl are proximity to a source, and ongoing exposure to PFAS through feeding and adsorption (Larson et al 2018). As most samples analysed were composites, it was not possible to relate PFAS concentrations to factors such as age or sex of ducks across Victoria. Analysis of individual samples collected from both Heart Morass (May 2017 February and May 2018) and Macleod Morass (May 2018) showed no apparent relationship between body weight and concentrations of PFOS + PFHxS (R^2 value <0.1). However, individual waterfowl from Macleod Morass showed strong differences in PFAS concentrations, with higher contamination for PFOS + PFHxS in Pink-eared Duck and Pacific Black Duck compared with the two species of Teal. Uncertainty exists in all chemical analysis, and PFAS concentrations in the same sample determined by the same laboratory can vary by ±20% or more (NMI 2018c). While composite samples for waterfowl provide a useful way to assess averaged PFAS concentrations in many wetlands and waterfowl species, there is uncertainty in the distribution of concentrations in individual species of waterfowl. For wetlands where risk to humans from consumption of waterfowl are elevated, this is addressed by analysing individual waterfowl specimens.

Other factors related to waterfowl ecology – particularly feeding, habitat preferences, migratory habits and breeding behaviour – are relevant to understanding the influence of potentially threatening processes such as pollution (Kingsford and Norman 2002). Yet there is currently insufficient evidence to determine if or how PFAS concentrations in different species of waterfowl are influenced by ecological factors. As all species of waterfowl exceeded trigger points for investigation, there is no indication to date that any of these autecological factors make a significant difference to the risk of accumulation of PFAS.

Human health risk assessment for consumption of waterfowl

From the 19 wetlands assessed in this study, concentrations of PFAS in waterfowl from three wetlands required health advisories for human consumption. Concentrations of PFAS in composite samples at Macleod Morass, Hospital Swamp and Heart Morass exceeded the FSANZ trigger points for investigation and were close to or exceeded consumption thresholds for children. This prompted the testing of individual ducks at Macleod Morass (Pacific Black Duck and Pink-eared Duck) and Heart Morass (Pacific Black Duck).

Concentrations of PFOS + PFHxS in waterfowl were above the LOR but below trigger points for investigation at most wetlands. Close to half of the wetlands also had concentrations of PFOS + PFHxS in waterfowl exceeding the FSANZ trigger points for investigation in one or more species, as shown in Figure 2. The highest concentrations of PFOS + PFHxS were in Pacific Black Duck and Pink-eared Duck at Macleod Morass, Pacific Black Duck from Heart Morass, and Hospital Swamp, respectively (Figure 2).

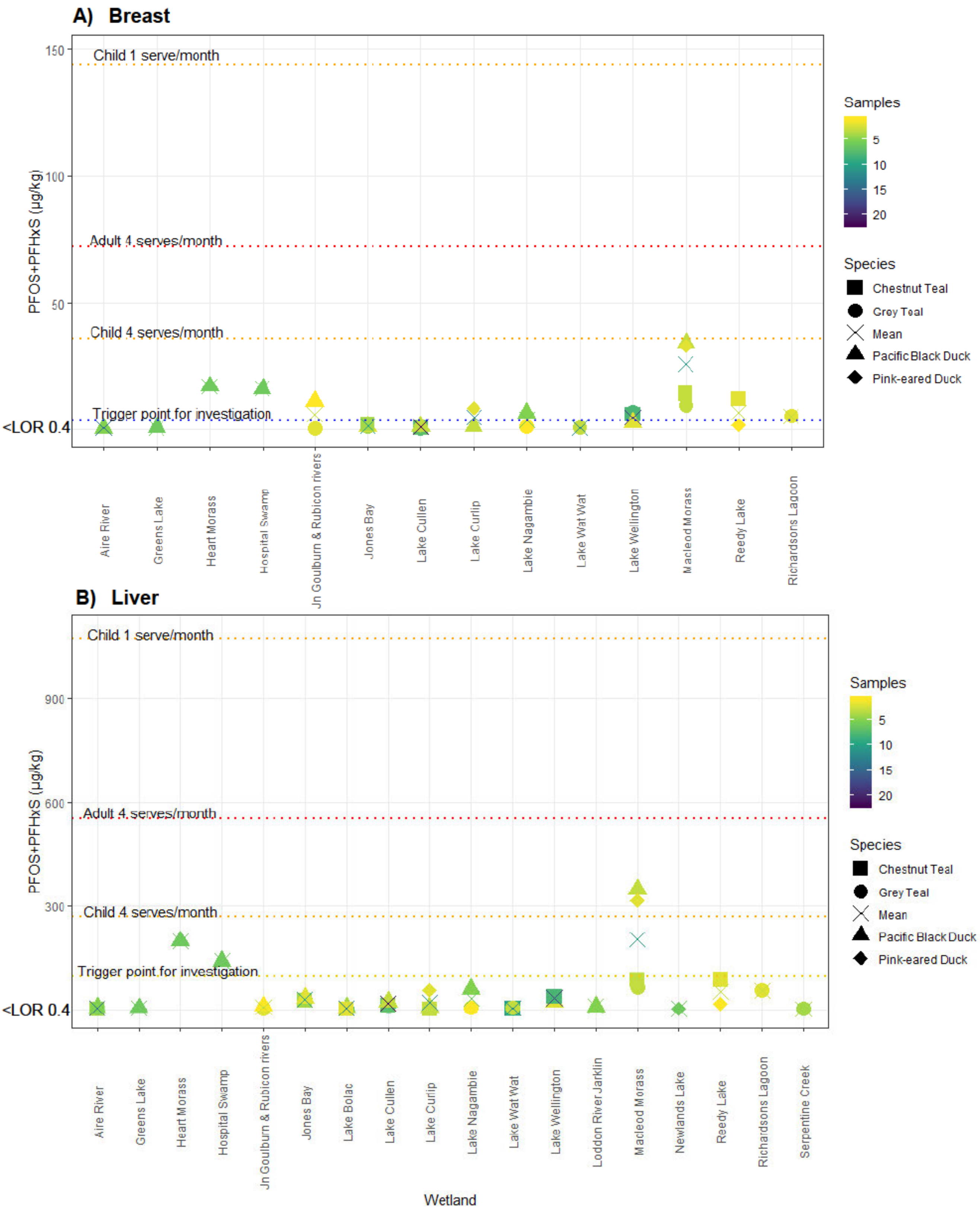


Figure 2 - Concentrations of PFOS + PFHxS in waterfowl A) Breast and B) Liver samples for those wetlands where they were detected above limits of reporting in relation to consumption thresholds for number of serves per month for children and adults. Colour of symbols indicates the number of individual waterfowl collected for each species (and total waterfowl for the mean). LOR = Limit of reporting.

EPA's consumption advice for waterfowl from wetlands across Victoria, based on concentrations of PFOS + PFHxS in liver and breast is summarised in Figure 3. Consumption of waterfowl from Heart Morass and the adjacent Dowd Morass should be avoided. Heart Morass and surrounding areas are affected by off-site runoff from the RAAF Base East Sale. Consumption should also be restricted at two other wetlands: Macleod Morass and Hospital Swamp. In both wetlands, concentrations of PFOS + PFHxS were close to or slightly exceeded the 'child four serves per month' consumption threshold for breast and livers.

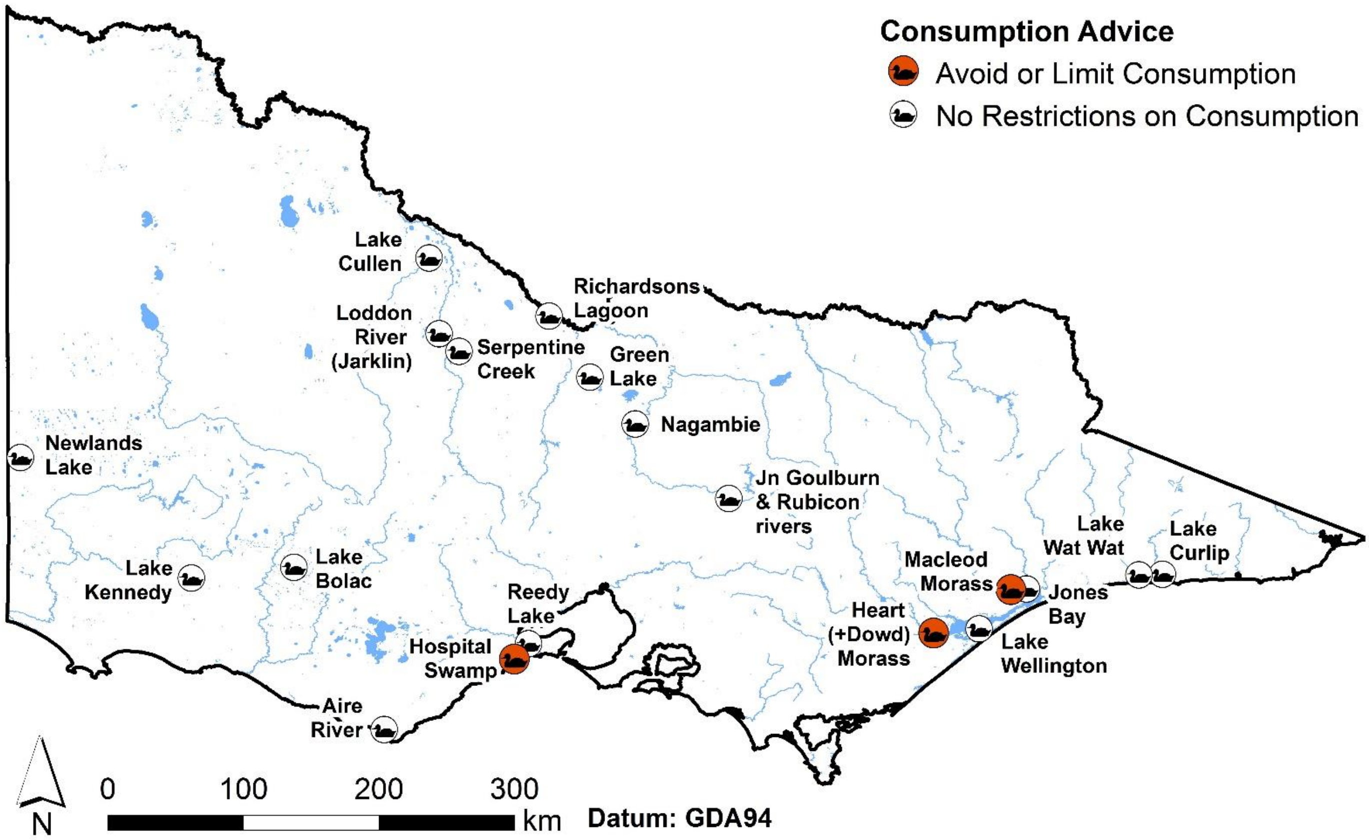


Figure 3 - Risk map of PFOS + PFHxS in waterfowl across Victorian wetlands. Symbols based on risk assessment and consumption.

Waterfowl from Macleod Morass

Macleod Morass had higher concentrations of PFAS in waterfowl compared with other wetlands across Victoria (Figure 2 and Figure 3). All four waterfowl species from Macleod Morass had PFOS + PFHxS concentrations exceeding trigger levels for investigation in breast meat; Pacific Black Duck slightly exceeded the child four serves per month consumption, while Pink-eared Duck was slightly below (Figure 2). Liver concentrations in only two species at Macleod Morass – Pacific Black Duck and Pink-eared Duck – exceeded the trigger point for investigation, but concentrations in these species also exceeded four serves per month consumption for children (Figure 2B).

It is estimated that children consuming four serves of waterfowl per month from Macleod Morass will reach or come close to reaching the TDI when consumption is averaged over a year. As a precaution, EPA recommends that for children consumption of waterfowl sourced from Macleod Morass is limited to one serve of breast meat per month (one serve = 75 g for children). EPA also recommends that adults and children do not eat liver from waterfowl sourced from Macleod Morass. By limiting their consumption to one serve of breast meat per month, children can safely consume waterfowl while not exceeding the TDI recommended by FSANZ.

Waterfowl from Hospital Swamp

Hospital Swamp had concentrations of PFAS exceeding trigger points for investigation in waterfowl (Pacific Black Duck) (Figure 2 and Figure 3).

EPA recommends that for children consumption of waterfowl breast meat should be limited to one serve (one serve = 75 g for children) per month of waterfowl collected from Hospital Swamp. EPA recommends adults and children should not eat waterfowl liver from Hospital Swamp. Concentrations of PFAS in Hospital Swamp did not exceed human health and ecological guideline values in waters, soils or sediments.

While PFOS + PFHxS concentrations in Reedy Lake exceeded drinking water guidelines, the evidence on which to base advice for consumption of waterfowl from Reedy Lake is not as strong, as there were only a small number of Chestnut Teal and Pink-eared Ducks collected. Given the proximity of these two wetlands, it would be prudent to similarly limit consumption of waterfowl (including Pacific Black Duck) from Reedy Lake until more evidence is available.

Waterfowl from Heart Morass

PFAS compounds PFOS + PFHxS were detected in the breast and liver composite samples for Pacific Black Duck from Heart Morass with both concentrations exceeding the trigger points for investigation (Figure 2 and Figure 3). Composite samples from multiple specimens accurately represent the distribution of individual waterfowl specimens in Heart Morass. PFOS + PFHxS concentrations in the breast and liver composite samples (17.1 and 197 µg/kg; Figure 2) were comparable with the arithmetic mean (16.1 and 183 µg/kg) of the individual samples. This enhances confidence in results based on PFAS concentrations in composite samples, comparison with previous sampling in Heart Morass and assessments in other wetlands.

Spatial and temporal variability in PFAS in Heart Morass

Within Heart Morass, three sampling events from different locations have been conducted. Most recently in May 2018, waterfowl were collected in the western area of Heart Morass. In February 2018, waterfowl were collected in the east of Heart Morass game reserve (Figure 4). The earliest waterfowl sampling by DoD in 2017 occurred in the middle of the wetland close to run-off from the RAAF Base East Sale (Figure 4). A map of Heart Morass showing the locations and dates where waterfowl and environmental samples were collected is shown in Figure 4. Concentrations of PFAS in sediments and waters varied markedly across Heart Morass. There were substantially lower concentrations towards the fringes of Heart Morass, both to the east and west (Figure 4). Higher concentrations were observed in 2017 in the middle of Heart Morass close to off-site runoff from the RAAF Base East Sale.

No additional environmental samples for PFAS were collected by EPA in 2018. The closest sites to the three waterfowl sampling locations where waters and sediments were collected are shown in Figure 4. Data collected by DoD (2017) suggest concentrations in waterfowl reflect concentrations in water, sediment and/or food sources. This corresponds with uptake from adsorption and consumption of contaminated food as the main biotic pathway, while exposure from sediment-associated PFAS was predicated as the main abiotic source of exposure rather than water-associated PFAS (Larson et al 2018).

Waterfowl species collected also varied slightly over these three events, although Pacific Black Duck was common to all. There may be differences in species, due to foraging behaviour, diet or habitat preferences, which may influence PFAS concentrations in waterfowl. Concentrations of PFAS in waterfowl across the Heart Morass may be highly variable both spatially or temporally. However, waterfowl sourced from the central part of Heart Morass (Field and Game Australia hunting reserve) is likely to pose a greater risk if consumed than those sourced from the edges. It is unclear whether spatial differences with disparate sampling locations would have a greater influence on PFAS concentrations in waterfowl compared with temporal changes, such as a decrease in PFAS concentrations due to the elimination of PFAS in the days and weeks after exposure. Given this uncertainty regarding PFAS concentrations in waterfowl across the wetland and surrounding areas, a precautionary approach is strongly advised to avoid consumption of waterfowl from Heart Morass and Dowd Morass as previously noted.

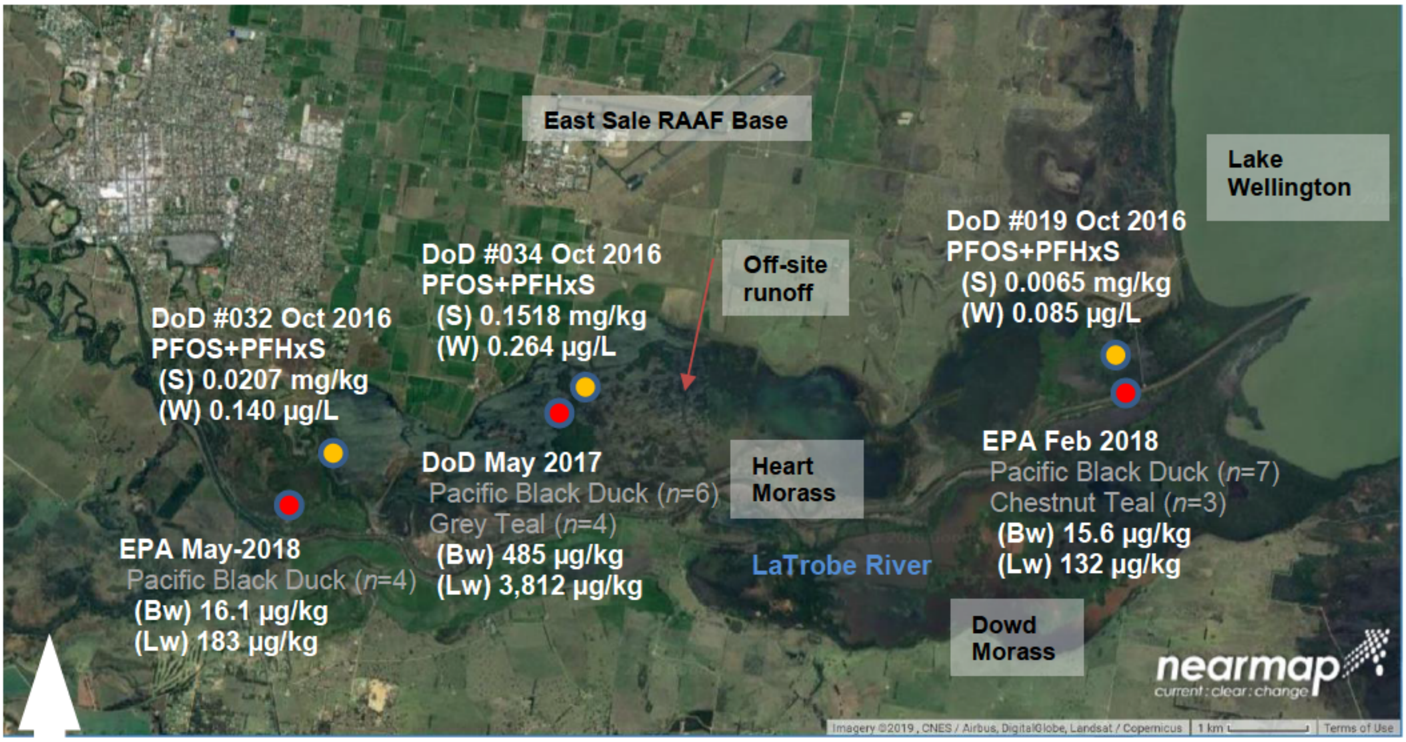


Figure 4 – Satellite imagery of Heart Morass and Dowd Morass. Markers show collection sites and concentrations of PFOS + PFHxS: mean waterfowl Lw = Liver and Bw = Breast (red); and DoD environmental site-specific samples, S = Sediment; W = Water (yellow); Data Sources: EPA May 2018, EPA Feb 2018, and Department of Defence, 2017), East Sale PFAS investigations. Imagery Source: nearmap, CNES / Airbus, Digital Globe, Landsat / Copernicus. Datum: GAD94.

Waterfowl ecology

In southern Australia, waterfowl typically breed when there is an abundance of food and water following rainfalls, typically in spring (Kingsford and Norman 2002). Above average rainfalls across Victoria in December 2017 may have encouraged waterfowl dispersion and breeding (Figure 5). However, the climate across Victoria in 2018 was at its driest since 1997, with approximately 25% less rainfall than the long-term (1961-1990) annual average (BOM 2019). Rainfalls were especially low during later summer and autumn leading up to and during collection of waterfowl in May, particularly in the Mallee, northern and central Victoria and the Gippsland region (Figure 6) (BOM 2019).

Waterfowl movements appear as a response to variation in resources that affect survival or alter breeding success (Roshier et al 2006). While Pacific Black Duck appear more sedentary (McEvoy et al 2015), Grey Teal and Pink-eared Duck display more nomadic and highly dispersive movements (Roshier et al 2008). Modelling suggests a smaller home range and more sedentary nature could attribute towards a higher uptake of PFOS in birds at sites impacted by AFFF (Larson et al 2018). Of those nine sites where PFAS in waterfowl exceeded trigger points for investigation, five were for Pacific Black Duck, which included the four highest concentrations in composite samples of waterfowl. However, the species and the number of specimens varied between wetlands. In wetlands where PFAS concentrations exceed guidelines, certain ecological traits in waterfowl may have an influence on exposure, but further research and assessment is required

Waterfowl populations are impacted by several threatening processes including water supply, drought, pollution, climate change, weeds and exotic species, and over-harvesting, yet limited information exists to assess the impacts and relationships between these processes (Kingsford and Norman 2002). Further research priorities for guiding the management of waterfowl and wetlands include: understanding waterfowl movements within Victoria; monitoring and assessment of wetland habitat; and understanding effects of pollution and hunting (Kingsford and Norman, 2002). New research on waterfowl ecology and tracking studies across Victoria would provide greater knowledge to better understand the distribution, diet and ecology of waterfowl (e.g. https://feathermap.ansto.gov.au/).

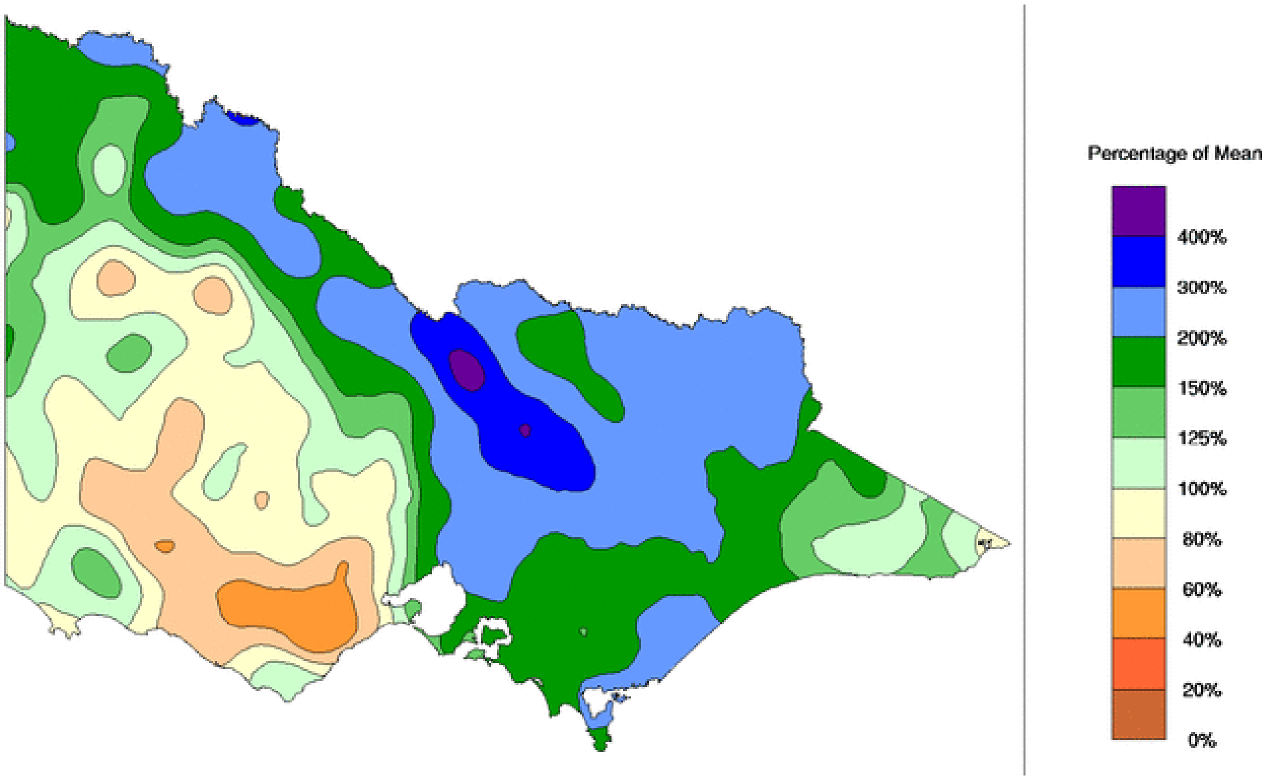


Figure 5 – Victorian rainfall totals for December 2017 as a percentage of the long-term (1961-1990) mean rainfall (BOM 2019).

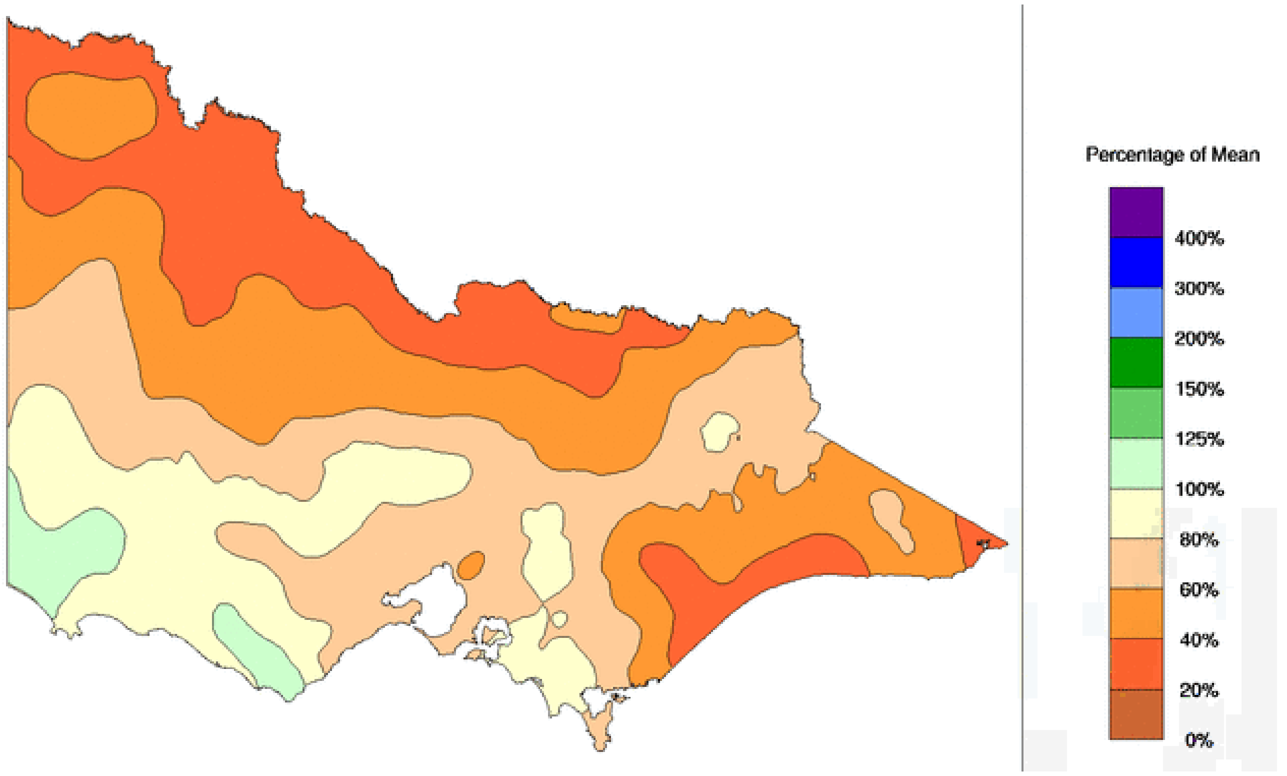


Figure 6 – Victorian rainfall totals for March - May 2018 as a percentage of the long-term (1961-1990) mean rainfall (BOM 2019).

PFAS toxicity, bioaccumulation and depuration

There are potential ecological impacts to aquatic ecosystems where elevated concentrations exceed the 99% species protection level for bioaccumulation. However, these default guideline values were not derived for air breathing animals nor are they protective of bioaccumulation in waterfowl (Australian Government 2016). However, the presence of PFAS in the environment or waterfowl tissues does not necessarily indicate an ecological impact, and similarly, contaminant concentrations in tissues do not directly relate to toxicity.

Depuration (elimination rates) in waterfowl were estimated using elimination kinetic models to estimate half-life of PFOS in the blood of two species of birds (Newsted et al 2007). Estimated depuration rates for waterfowl and other birds were much shorter than in mammals, with Mallards (closely related to Pacific Black Duck) and quail having estimated half-lives of 14 and 21 days, respectively. Depuration in chickens was determined from experiments for PFOS (16 – 125 days) and PFOA (4 – 5 days) (Yoo et al 2009, Yeung et al 2009). By comparison, depuration half-lives for PFOS in mammals range from 100 days in rats, 150 days in monkeys and 5.5 years for humans (CRC CARE, 2018). Depuration rates and half-lives vary between species, but PFOS and PFOA cannot be metabolised by mammals and are subsequently excreted in urine and faeces (Stahl et al 2011). PFAS uptake and depuration also differs between various organs (Yoo et al 2009). Assuming no additional PFAS exposure, once animals are removed from contamination sources PFAS will gradually be eliminated with times dependent on the initial concentration in different organs for each species.

Concentrations of PFOS have been decreasing in biota globally following the voluntary phase out by four of the five main PFOS manufacturers in the USA since 2002 (Armitage et al 2009), while concentrations of alternative PFAS, including shorter and long-chain perfluorinated carboxylic acids (PFCAs), continue to be used and may be increasing (Brendel et al 2018, Wang et al 2013). Further information on PFAS bioaccumulation in aquatic ecosystems will provide a greater ability to determine its environmental fate and transport to better assess and manage risks from emerging contaminants (Pi et al 2017).

Sources of PFAS

There is no clear evidence of any major source of PFAS at wetlands other than Heart Morass and Lake Wellington. Hospital Swamp and Macleod Morass are downstream of urban areas where stormwater may transport PFAS from industrial, commercial and residential areas. Similarly, Reedy Lake receives water from the Barwon River downstream of Geelong, where PFOS + PFHxS was elevated compared with water drinking water guidelines. Low but detectable concentrations of PFAS in wetlands away from developed areas such as Lake Cullen and the Loddon River near Jarklin indicate the widespread distribution of these compounds in the environment.

Except for the Loddon River, all sites with PFAS residues detected in soils, sediment and/or waters also had concentrations of PFOS + PFHxS in waterfowl above the trigger points for investigation (Table 3). This is despite environmental sample concentrations being relatively low in most sites except Reedy Lake where PFOS exceeded drinking guideline values for PFOS + PFHxS. While initial PFAS concentrations in waterfowl in Reedy Lake appear below the consumption thresholds, only a few specimens (n = 3) of Grey Teal and Pink-eared Duck were analysed, and concentrations of PFAS in Pacific Black Duck collected nearby from Hospital Swamp were elevated.

Conclusions

PFAS is widespread and concentrations in waterfowl, sediment, soil and water were highly variable between different wetlands across Victoria. Higher concentrations of PFAS appear to be related to either point sources or other unknown potential sources in urban runoff. EPA will continue to work to identify sources and manage risks relating to PFAS and other emerging contaminants. In wetlands where PFAS was detected, waterfowl also appeared to have PFAS concentrations exceeding FSANZ screening points for investigation.

The risk assessment suggests a consumption advisory to avoid eating waterfowl sourced from Heart Morass and Dowd Morass continues to be necessary, consistent with earlier EPA advice. For consumption of waterfowl at Macleod Morass and Hospital Swamp, EPA advises that adults and children do not eat waterfowl liver, and to limit consumption of breast meat for children to one serve per month (75 g). While PFAS concentrations were higher in Pacific Black Duck and Pink-eared Duck in Macleod Morass compared with Chestnut Teal or Grey Teal, sampling numbers were not high enough to draw conclusions as to the differences between species.

It was only possible to collect waterfowl for testing from a limited number of wetlands. It is therefore recommended that consumers of waterfowl should generally exercise caution when consuming waterfowl from sites near wetlands where current health advisories exist. For example, Reedy Lake is within 2 km of Hospital Swamp and waterfowl can freely move between these wetlands. Unless further evidence demonstrates otherwise, waterfowl harvested from Reedy Lake may be the same of those inhabiting Hospital Swamp. Further analysis of individual waterfowl will be completed by mid-2019 to determine the range of PFAS concentrations in waterfowl at this site to better inform advice for human consumption. In the interim, EPA recommends a precautionary approach for adults and children in restricting consumption of all species sourced from the affected wetlands

EPA is committed to providing ongoing advice to better understand the risk of exposure to PFAS and other emerging contaminants. Further investigation will continue to improve our understanding and management of the potential risks of PFAS to the environment and human health. Under the direction of EPA's Chief Environmental Scientist, EPA will continue to assess PFAS in the environment. This includes re-analysis of PFAS in individual waterfowl specimens from Hospital Swamp; further sampling for PFAS in sediments and waters to identify potential sources around Hospital Swamp and Macleod Morass; assessing ecological impacts; and engaging with the Interagency Working Group for Emerging Contaminants.

References

Antweiler, R. C., & Taylor, H. E. (2008) Evaluation of statistical treatments of left-censored environmental data using coincident uncensored data sets: I. Summary statistics. *Environmental science & technology*, ***42***, 3732-3738.

ARI (2018) Unpublished data, Macleod Morass duck liver weights. Arthur Rylah Institute for Environmental Research (ARI), Department of Environment, Land, Water and Planning, State Government of Victoria.

Armitage, J. M., Schenker, U., Scheringer, M., Martin, J. W., MacLeod, M., & Cousins, I. T. (2009). Modelling the global fate and transport of perfluorooctane sulfonate (PFOS) and precursor compounds in relation to temporal trends in wildlife exposure. *Environmental science & technology*, ***43***, 9274-9280.

Australian Government, Department of Health (2017) Health based guidance values for PFAS for use in site investigations in Australia. http://www.health.gov.au/internet/main/publishing.nsf/content/ohp-pfas-hbgv.htm

Australian Government, Department of The Environment and Energy (2016) Commonwealth Environmental Management Guidance on Perfluorooctane Sulfonic Acid (PFOS) and Perfluorooctanoic Acid (PFOA), Draft dated October 2016 and published December 2016: http://www.environment.gov.au/protection/chemicals-management/pfas

Brendel, S., Fetter, É., Staude, C., Vierke, L., & Biegel-Engler, A. (2018). Short-chain perfluoroalkyl acids: environmental concerns and a regulatory strategy under REACH. *Environmental Sciences Europe*, *30*(1), 9.

Bureau of Meteorology (BOM) (2019) Climate data online, average annual, seasonal and monthly rainfall, http://www.bom.gov.au/climate/current/annual/vic/summary.shtml

Canadian Government (2017) Canadian Environmental Protection Act, 1999. Canadian Federal Environment Quality Guidelines, Perfluorooctane Sulfonate (PFOS), February 2017. Environment and Climate Change Canada.

CRC CARE (2018) Practitioner guide to risk-based assessment, remediation and management of PFAS site contamination, CRC CARE Technical Report no. 43, CRC for Contamination Assessment and Remediation of the Environment, Newcastle, Australia. https://www.crccare.com/files/dmfile/CRCCARETechreport43_PFASpractitionerguide_web.pdf

Department of Defence (DoD) (2017) Detailed site investigation: RAAF Base East Sale – Per- and Poly-fluoroalkyl Substances (PFAS) Investigations. Senversa, June 2017, http://www.defence.gov.au/environment/PFAS/EastSale/publications.asp

enHealth (2012) Environmental Health Risk Assessment, Guidelines for assessing human health risks from environmental hazards, enHealth, Commonwealth of Australia, Canberra

enHealth (2018) Expert Health Panel for Per- and Poly-Fluoroalkyl Substances (PFAS), Report to the Minister, March 2018, http://www.health.gov.au/internet/main/publishing.nsf/Content/ohp-pfas-expert-panel.htm

EPA (2017) Incoming water standards for aquatic ecosystem protection: PFOS and PFOA. EPA publication 1633.2, August 2017, https://www.epa.vic.gov.au/our-work/publications/publication/2017/august/1633-2

EPA (2018) Consumption advice for recreationally caught game – East Gippsland. EPA publication 1672.2, August 2018, https://www.epa.vic.gov.au/our-work/publications/publication/2018/august/1672-2

EPA (2018) Assessment of potential human health risk to duck hunters who consume ducks sourced from the Heart Morass, Lake Bolac and Hird Swamp. Internal Report.

EPA's (2018) Interim position statement on PFAS, EPA publication 1669.2 https://www.epa.vic.gov.au/our-work/publications/publication/2018/august/1669-2

EPA (2018) Monitoring the environment: EPA's fixed marine monitoring sites, https://www.epa.vic.gov.au/our-work/monitoring-the-environment/monitoring-victorias-marine-environment/what-marine-monitoring-do-we-do

Expert Panel Report prepared for the Australian Government (2018) http://www.health.gov.au/internet/main/publishing.nsf/Content/ohp-pfas-expert-panel.htm

Food Standards Australia New Zealand (2009) Principles and Practices of Dietary Exposure Assessment for Food Regulatory Purposes, August 2009, http://www.foodstandards.gov.au/publications/Pages/Principles-and-Practices-of-Dietary.aspx

Food Standards Australia New Zealand (FSANZ) (2017) Perfluorinated chemicals in food – April 2017. http://www.health.gov.au/internet/main/publishing.nsf/Content/ohp-pfas-hbgv.htm

GMA (2017) Estimates of harvest for duck and Stubble Quail in Victoria. Results from surveys of Victorian Game Licence Holders in 2017. Game Management Authority, Victorian Government, 2017, http://www.gma.vic.gov.au/__data/assets/pdf_file/0004/373603/Game-Bird-Harvest-Report-2017-V2-FOR-WEB.pdf

Goudey, R. (2007) Do statistical inferences allowing three alternative decisions give better feedback for environmentally precautionary decision-making?. *Journal of Environmental Management*, **85**, 338-344.

Heads of EPAs Australia and New Zealand (HEPA) (2018) PFAS national environment management plan (NEMP), January 2018. https://www.epa.vic.gov.au/your-environment/land-and-groundwater/pfas-in-victoria/pfas-national-environmental-management-plan

Kingsford, R. T. and Norman, F. I. (2002) Australian waterbirds -products of the continent's ecology. *Emu* 102, 47–69.

Larson, E.S., Conder, J.M., and Arblaster, J.A. (2018) Modelling avian exposures to perfluoroalkyl substances in aquatic habitats impacts by historical aqueous film forming foam releases. *Chemosphere*, **201**, 335–341.

McEvoy JF, Roshier DA, Ribot RFH, Bennett ATD. (2015) Proximate cues to phases of movement in a highly dispersive waterfowl, *Anas superciliosa*. *Movement Ecology,* **3**, 21. https://movementecologyjournal.biomedcentral.com/articles/10.1186/s40462-015-0048-3

Menkhorst, P., Rogers, D. I., and Clarke, R. (2017) *The Australian bird guide*. CSIRO Publishing.

Museums Victoria (2017) Water birds in Museums Victoria Collections. Accessed 12 January 2019, https://collections.museumvictoria.com.au/search?keyword=Water+birds

National Environment Protection (Assessment of Site Contamination) Measure (NEPM) (1999) ASC NEPM.

National Measurement Institute (2018b) Per- and Poly- fluoroalkyl Substances (PFAS), website accessed 15 December 2018, https://www.measurement.gov.au/Services/EnvironmentalTesting/Pages/PFAS.aspx

National Measurement Institute (2018b) PFAS Environmental Testing Services, website accessed 15 December 2018, https://www.measurement.gov.au/Publications/FactSheets/Documents/NMI63.pdf

National Measurement Institute (2018c) Proficiency Test Report AQA 18-09 PFAS in soil, water, fish and prawn, December 2018. https://www.measurement.gov.au/Publications/ProficiencyStudyReports/Pages/default.aspx

Newton, I. (2008) *The Migration Ecology of Birds*. Amsterdam; London: Elsevier-Academic, 2008.

Roshier D.A., Klomp N.I. & Asmus M. 2006. Movements of a nomadic waterfowl, Grey Teal *Anas gracilis*, across inland Australia – results from satellite telemetry spanning fifteen months. *Ardea* **94**, 461–475.

Roshier, D. A., Asmus, M., and Klaassen, M. (2008) What drives long-distance movements in nomadic grey teal *Anas gracilis* in Australia? *The Ibis,* **150**, 474–484.

Stahl, T., Mattern, D. and Brunn, H. (2011) Toxicology of perfluorinated compounds. *Environmental Sciences Europe*, **23**, 1–52.

Victorian Government (2018) Victorian Government Data Directory, www.data.vic.gov.au

Wang, Z., Cousins, I. T., Scheringer, M., and Hungerbühler, K. (2013). Fluorinated alternatives to long-chain perfluoroalkyl carboxylic acids (PFCAs), perfluoroalkane sulfonic acids (PFSAs) and their potential precursors. *Environment international*, ***60***, 242-248.

Warne, M. St.J., Batley, G.E., van Dam, R.A., Chapman, J.C., Fox, D.R., Hickey, C.W. and Stauber, J.L. (2015) Revised Method for Deriving Australian and New Zealand Water Quality Guideline Values for Toxicants. Prepared for the Council of Australian Government's Standing Council on Environment and Water (SCEW). August 2015.

Yoo H, Guruge KS, Yamanaka N, Sato C, Mikami O, Miyazaki S, Yamashita N, Giesy JP (2009) Depuration kinetics and tissue disposition of PFOA and PFOS in white leghorn chickens (*Gallus gallus*) administered by subcutaneous implantation. *Ecotoxicology and Environmental Safety*, **72**, 26–36.

Yeung LW, Loi EI, Wong VY, Guruge KS, Yamanaka N, Tanimura N, Hasegawa J, Yamashita N, Miyazaki S, Lam PK (2009) Biochemical responses and accumulation properties of long-chain perfluorinated compounds (PFOS / PFDA / PFOA) in juvenile chickens (*Gallus gallus*). *Archives of Environmental Contamination and Toxicology*, **57**, 377–386.

Emerging contaminants assessment 2020: Summary of Mildura results

EPA VICTORIA | Environment Protection Authority Victoria

VICTORIA State Government

Publication 1924 December 2020 **Summary report**

Executive summary

In March 2020, Environment Protection Authority Victoria (EPA) undertook targeted sampling of water, sediment and soil at eight locations in Mildura, Victoria.

The results for all emerging contaminants were consistent with concentrations EPA has observed in previous studies, with the exception of metals at Horseshoe Lagoon and in Lake Hawthorn (Sardina et al. 2019; Sharp et al 2020; EPA publication 1870, May 2020). Concentrations of PFAS in surface waters, sediments and soil samples were relatively low. In water, measured concentrations of PFOS did not exceed the ecological 95 per cent species protection guideline value (0.13 µg/L) (PFAS NEMP 2.0). In soil, PFBA was the only PFAS compound detected (0.0045 mg/kg) and from a site with a high intensity agriculture land-use. Currently there are no guidelines for PFBA. In sediment, PFAS concentrations were below the detection limit at all sites.

Of the 106 pesticides analysed, only four were detected in the environment. In water, herbicides atrazine, simazine and diuron were detected across different land-uses, with one simazine concentration exceeding the ecological 99 per cent species protection guideline level at a site with urban industrial land-use. In soil, all pesticides were below the limit of reporting, and, in sediment, only the insecticide bifenthrin was detected at two urban sites (residential and industrial). Currently there are no guidelines for bifenthrin in the environment.

Metals were found across all land-use types in urban and regional Mildura. In water, six metals (As, Cr, Cu, Pb, Ni, Zn) exceeded water quality guidelines, and the highest concentrations were found in the Horseshoe Lagoon (background site). Further water sampling is recommended to gain a better understanding of the natural variation of metal concentrations in water bodies in Mildura. In sediment and soil, metals were frequently detected across all land-use types, but concentrations did not exceed the current guidelines.

This assessment enables EPA to further identify the extent and magnitude of emerging and legacy contaminants in regional Victoria, to inform where there may be priority areas, inform regulatory responses, and identify sectors to work with to prevent and reduce environmental pollution and harm. The results suggest pesticide and PFAS levels in soils are not increased in this region, however additional sampling would be required to confirm this. This document should be read in conjunction with EPA publication 1879: *Emerging contaminants 2019-20: Summary of results*.

Definitions and methodology

Selection of sites

EPA selected sites representing five land-use types: background, low-intensity agriculture (grazing), high-intensity agriculture (cropping, horticulture), urban residential, and urban industrial.

The background site, Horseshoe Lagoon, represented a natural environment with no or minimal anthropogenic impact (e.g. wind-blown dust from agricultural areas). However, it is noted that at the time of sampling, the site was largely impacted by blue-green algae due to drier conditions, and nutrient inputs from large flocks of water birds.

Water and sediment samples were collected at seven sites, and soil samples at eight sites. All sampling sites were within 30 km of Mildura.

Authorised and published by
Environment Protection Authority Victoria
200 Victoria Street, Carlton VIC 3053
W epa.vic.gov.au | **T** 1300 372 842 (1300 EPA VIC)

Sampling methodology

The methods for sample collection, handling, transporting, storing and quality assurance and control were consistent with EPA publication IWRG 701 (2009) and PFAS National Environmental Management Plan (NEMP) (2018). Emerging contaminants were determined using USEPA 8270, USEPA 537 and USEPA-821-R-11-007, *Pesticide Analytical Manual* (1999), AS4479, USEPA 3050, 200.7, 6010, 200.8 and 6020 methods at the National Measurement Institute. Out of 33 PFAS-compounds analysed, five most frequently detected were PFHxS, PFOS, PFBS, PFBA and PFOA. Out of 106 pesticides analysed, four detected were atrazine, bifenthrin, diuron and simazine.

Results

PFAS: PFOS, PFHxS, PFBS, PFBA and PFOA

The concentrations of PFAS compounds in water, sediment and soil samples across the five land-use types were found to be relatively low. At the background site, concentrations of PFOS, PFHxS, PFBS, PFBA and PFOA were lower than the limit of reporting (LOR) in water, sediment and soil (Table 1). In water, across other land-uses, maximum concentrations of PFHxS, PFOS, PFBS, PFBA and PFOA were 0.026, 0.011, 0.028, 0.11 and 0.021 μg/L respectively. In soil, PFBA was the only PFAS compound detected at a concentration of 0.0045 mg/kg, and in a high-intensity agriculture site. For PFOS, PFHxS, PFBS and PFOA, all sites had concentrations below LOR (Table 1) in both soil and sediment.

Table 1. Range of concentrations and % samples detected for PFHxS, PFOS, PFBS, PFBA and PFOA[#].

PFAS	Water (n = 7)		Sediment (n = 7)		Soil (n = 8[##])	
	Range (μg/L)	Detected (%)	Range (mg/kg)	Detected (%)	Range (mg/kg)	Detected (%)
PFHxS	<0.0002[†] – 0.026	71	<0.001	0	<0.001	0
PFOS	<0.0003[†] – 0.011	57	<0.002	0	<0.002	0
PFBS	<0.0005[†]– 0.028	57	<0.001	0	<0.001	0
PFBA	<0.0005[†] – 0.11	57	<0.002	0	<0.002 – 0.0045	13
PFOA	<0.0005[†] – 0.021	29	<0.001	0	<0.001	0

[#]The minimum concentration is the LOR for each PFAS. Number of sites (n) per land-use type: background (1), low-intensity (1), high-intensity agriculture (1), mixed land-use (2), urban residential (1) and urban industrial (1).

[##]An additional sample was collected from a low-intensity agricultural site.

[†]For three sites (background, low- and high-intensity agriculture) LOR was raised to a standard level from ultra-trace due to analytical interferences.

Pesticides

Concentrations of pesticides in surface waters varied (Table 2). Two herbicides were detected: the urea diuron at two sites (0.21 μg/L and 0.28 μg/L; low- and high-intensity agriculture), and the triazine simazine at one urban industrial site (0.34 μg/L). Bifenthrin was the only insecticide detected in water (14 per cent) at concentrations ranging from <0.005 to 0.019 μg/L. All fungicides were below the LOR (Table 2).

In sediment, only the synthetic pyrethroid bifenthrin was detected at two urban sites (residential and industrial) (Table 2).

In soil, all pesticide concentrations were below the LOR, including the legacy insecticides (e.g. DDT and dieldrin), organophosphates (e.g. chlorpyrifos) and carbamates (e.g. pirimicarb) (Table 2).

Table 2. Range and % of samples' detected concentrations for key pesticides in water, sediment and soils#.

		Water (*n* = 7)		**Sediment** (*n* = 7)		**Soil** (*n* = 8)	
Compound	**Mode of action**	**Range (µg/L)**	**Detected (%)**	**Range (µg/kg)**	**Detected (%)**	**Range (µg/kg)**	**Detected (%)**
Organochlorines	Insecticide	<0.005	0	<1	0	<1	0
Organophosphates		<0.01	0	<1	0	<1	0
Synthetic pyrethroid (bifenthrin)		<0.005 – 0.019	14	<1 – 5.3	29	<1	0
Synthetic pyrethroids (others)		<0.005	0	<1	0	<1	0
Triazines (atrazine)	Herbicide	<0.01 – 0.092	14	<10	0	<10	0
Triazines (simazine)		<0.01 – 0.34	14	<10	0	<10	0
Triazines (others)		<0.01	0	<10	0	<10	0
Urea (Diuron)		<0.01 – 0.28	29	<10	0	<10	0
Fungicides	Fungicide	<0.01	0	<10	0	<10	0
Miscellaneous	Misc	<0.01	0	<10	0	<10	0

#The minimum concentration is the LOR for each pesticide. Number of sites (n) per land-use type:
background (1), low-agriculture (1 – 2), high-agriculture (1), mixed land-use (2), urban residential (1) and urban industrial (1).

Metals

Metals (11 out of 13) were found across different land-use types in urban and regional Mildura. In water, six metals (As, Cr, Cu, Pb, Ni, Zn) exceeded current environmental water quality guidelines. Horseshoe Lagoon had elevated concentration of arsenic (11 µg/L), total chromium (18 µg/L), copper (13 µg/L), lead (10 µg/L), nickel (15 µg/L) and zinc (37 µg/L). This was most likely due to a combination of factors, such as naturally elevated levels of organic material, low pH, high turbidity and a recent algal bloom. Two urban wetlands (Dunning and Etiwanda) had slightly elevated concentrations of total arsenic (3.1 µg/L), exceeding the 99 per cent ecological species protection level (0.8 µg/L). In addition, Etiwanda wetland, which is an urban industrial site, had elevated concentration of chromium (2 µg/L), exceeding the 95 per cent ecological species protection level (1 µg/L), and zinc (11 µg/L), exceeding the 95 per cent protection level (8 µg/L). Overall, chromium concentrations were elevated (1.1 – 1.3 µg/L) along the Murray River, across different land-use types (including background), exceeding the 90 per cent protection level (1.8 µg/L). It is recommended that further water sampling is conducted to gain a better understanding of the natural variation of metal concentrations in these waterbodies.

In sediment and soil samples, 11 of the 13 metals were detected at all sites (As, Be, Bo, Cd, Cr, Co, Cu, Pb, Mn, Ni, Zn). In sediment, metal concentrations were below guidelines, except for nickel in the background site Horseshoe Lagoon (25 mg/kg). In soil, all detected concentrations of metals were below ecological and human health guidelines.

Limitations of the study

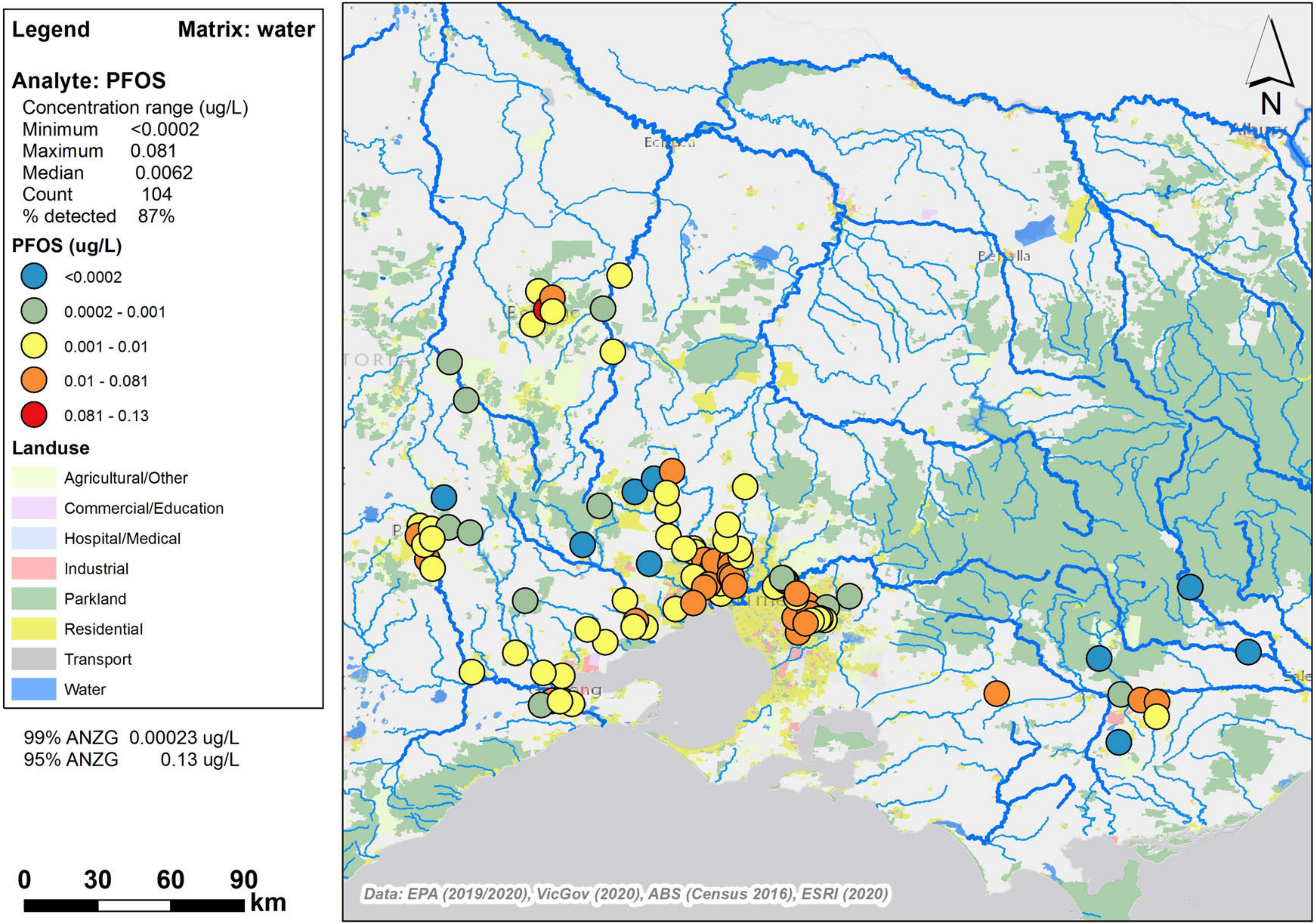
- The small number of samples restricts interpretation to specific location.
- Further spatial and temporal replication would provide a greater understanding of and confidence in the variation of concentrations of contaminants in the environment.
- Environmental samples (water, sediment, soil) should be combined with biota (fish, macroinvertebrate) samples to gain a better understanding of the ecosystem level impacts of emerging contaminants.

Supplementary Table 1. Summary of PFAS compound groups and limits of reporting in freshwaters, sediments and soils.

Family	PFAS group	PFAS compound name	PFAS	CAS registry	Sediment / soil LOR	Water LORs
Perfluorinated	Perfluoroalkyl carboxylic acids	Perfluorobutanoic acid	PFBA	375-22-4	<0.002	<0.005
		Perfluoropentanoic acid	PFPeA	2706-90-3	<0.002	<0.001
		Perfluorohexanoic acid	PFHxA	307-24-4	<0.001	<0.0005
		Perfluoroheptanoic acid	PFHpA	375-85-9	<0.001	<0.0005
		Perfluorooctanoic acid	PFOA	335-67-1	<0.001	<0.0005
		Perfluorononanoic acid	PFNA	375-95-1	<0.001	<0.0005
		Perfluorodecanoic acid	PFDA	335-76-2	<0.001	<0.005
		Perfluoroundecanoic acid	PFUdA	2058-94-8	<0.002	<0.005
		Perfluorododecanoic acid	PFDoA	307-55-1	<0.002	<0.005
		Perfluorotridecanoic acid	PFTrDA	72629-94-8	<0.002	<0.001
		Perfluorotetradecanoic acid	PFTeDA	376-06-7	<0.002	<0.001
		Perfluorohexadecanoic acid	PFHxDA	67905-19-5	<0.002	<0.001
		Perfluorooctadecanoic acid	PFODA	16517-11-6	<0.005	<0.002
	(n:2) Fluorotelomer unsaturated carboxylic	8:2 Fluorotelomer unsaturated	FOUEA	70887-84-2	<0.001	<0.001
	Perfluoroalkane sulfonic acids	Perfluorobutanesulfonic acid	PFBS	375-73-5	<0.001	<0.0005
		Perfluoropentane sulfonic acid	PFPeS	2706-91-4	<0.001	<0.0005
		Perfluorohexane sulfonic acid	PFHxS	355-46-4	<0.001	<0.0002
		Perfluoroheptane sulfonic acid	PFHpS	375-92-8	<0.001	<0.0005
		Perfluorooctane sulfonic acid	PFOS	1763-23-1	<0.002	<0.0002
		Perfluorononane sulfonic acid	PFNS	68259-12-1	<0.001	<0.0005
		Perfluorodecane sulfonic acid	PFDS	335-77-3	<0.001	<0.0005
	Perfluoroalkane sulfonamides	Perfluorooctane sulfonamide	PFOSA	754-91-6	<0.001	<0.0005
Polyfluorinated	N-Methyl perfluoroalkane sulfonamides	N-Methyl perfluorooctane	N-MeFOSA	31506-32-8	<0.002	<0.002
	N-Ethyl perfluoroalkane sulfonamides	N-Ethyl perfluorooctane sulfonamide	N-EtFOSA	4151-50-2	<0.005	<0.005
	N-Methyl perfluoroalkane	N-Methyl perfluorooctane	N-	2355-31-9	<0.002	<0.002
	N-Ethyl perfluoroalkane sulfonamidoacetic	N-Ethyl perfluorooctane	N-EtFOSAA	2991-50-6	<0.002	<0.002
	N-Methyl perfluoroalkane	N-Methyl perfluorooctane	N-MeFOSE	24448-09-7	<0.005	<0.005
	N-Ethyl perfluoroalkane	N-Ethyl perfluorooctane	N-EtFOSE	1691-99-2	<0.005	<0.005
	(n:2) Fluorotelomer sulfonic acids	4:2 Fluorotelomer sulfonic acid	4:2 FTS	757124-72-4	<0.001	<0.001
		6:2 Fluorotelomer sulfonic acid	6:2 FTS	27619-97-2	<0.001	<0.001
		8:2 Fluorotelomer sulfonic acid	8:2 FTS	39108-34-4	<0.001	<0.001
		10:2 Fluorotelomer sulfonic acid	10:2 FTS	120226-60-0	<0.002	<0.001
	Polyfluoroalkyl phosphoric acid diesters	8:2 Fluorotelomer phosphate diester	8:2 diPAP	678-41-1	<0.002	<0.002

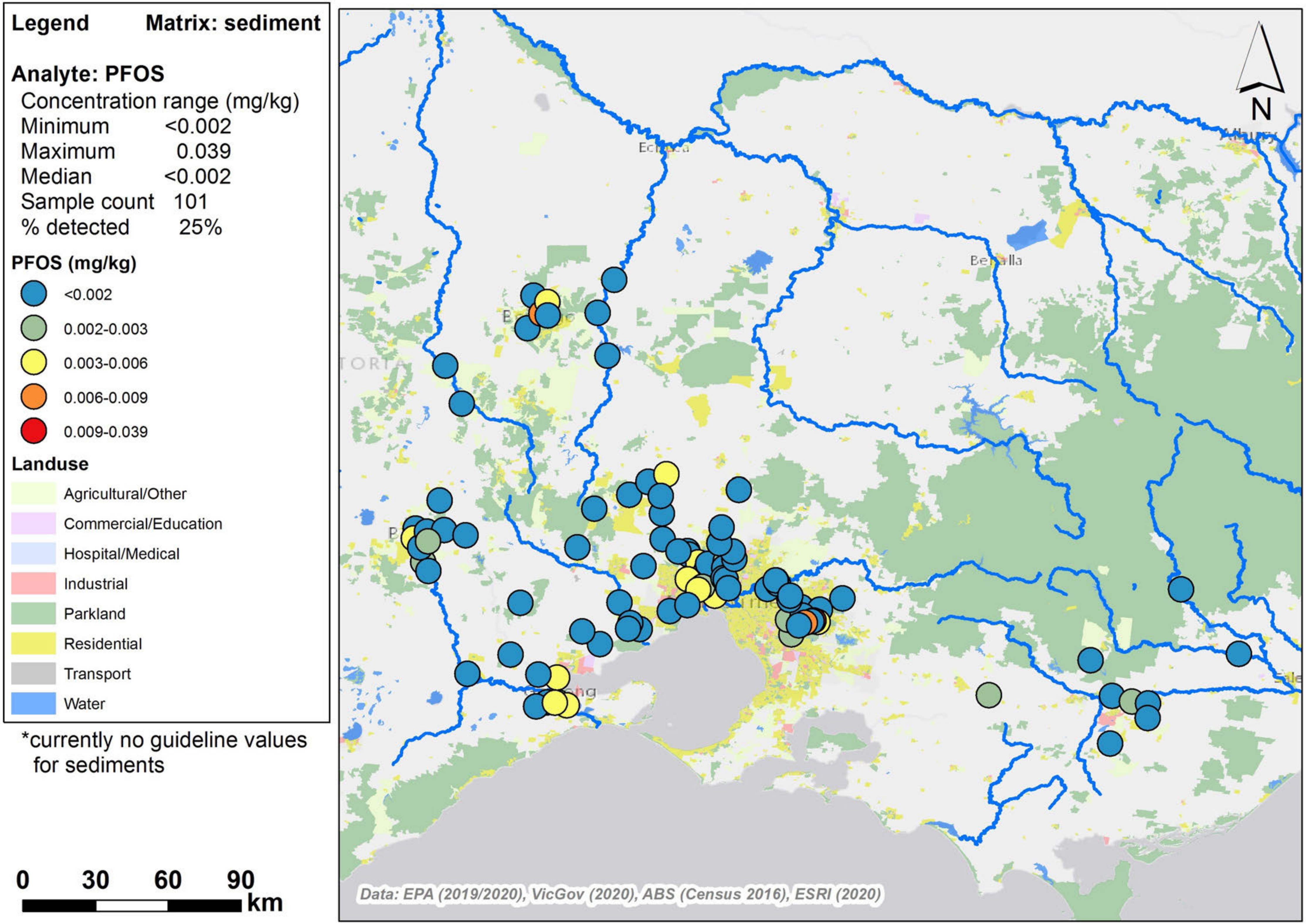
Supplementary Table 2A. PFAS concentrations and detection frequencies in waters.

	Chemical	PFHxS	PFOS	PFOA	6:2 FTS	PFBS	PFBA	PFDS	PFDoDA	PFHpA	PFHxA	PFNA	PFOSA	PFPeS	PFPeA	PFUnDA
	Units	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
Guidelines																
NEMP Health-based guideline values - drinking water		0.07	0.07	0.56	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
NEMP Health-based guideline values - recreational water		2	2	5.6	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
NEMP Aquatic Ecosystems (99% level)		NA	0.00023	19	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
NEMP Aquatic Ecosystems (95% level)		NA	0.13	220	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
NEMP Aquatic Ecosystems (90% level)		NA	2	632	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	LOR	<0.0002	<0.0002	<0.0005	<0.001	<0.0005	<0.005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.001	<0.0005
	Maximum	0.068	0.081	0.036	0.071	0.023	0.074	0.021	0.005	0.038	0.57	0.014	0.005	0.009	0.039	0.005
	Count	103	103	103	103	103	103	103	103	103	103	103	103	103	103	103
	%Detected	86%	88%	82%	11%	73%	76%	52%	5%	68%	81%	52%	2%	45%	69%	1%
Ambient Landuse	**Statistic**	**PFHxS**	**PFOS**	**PFOA**	**6:2 FTS**	**PFBS**	**PFBA**	**PFDS**	**PFDoDA**	**PFHpA**	**PFHxA**	**PFNA**	**PFOSA**	**PFPeS**	**PFPeA**	**PFUnDA**
Background (n = 17)	Min	<0.0002	<0.0002	<0.0005	<0.001	<0.0005	<0.005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.001	<0.0005
	Max	0.0017	0.0026	0.0021	<0.001	0.0009	0.0490	0.0016	0.0008	0.0008	0.0039	0.0005	0.0005	0.0005	0.0025	0.0005
	No. Detected	53%	53%	35%	0%	29%	47%	6%	6%	18%	29%	12%	0%	0%	18%	0%
High-intensity agriculture (*n* = 10)	Min	<0.0002	<0.0002	<0.0005	<0.001	<0.0005	<0.005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.001	<0.0005
	Max	0.0290	0.014	0.0056	0.0710	0.0026	0.0150	0.0007	<0.0005	0.0031	0.0063	0.0008	<0.0005	0.0021	0.0039	<0.0005
	No. Detected	60%	80%	60%	10%	30%	60%	10%	0%	30%	60%	10%	0%	20%	40%	0%
Low-intensity agriculture (*n* = 19)	Min	<0.0002	<0.0002	<0.0005	<0.001	<0.0005	<0.005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.001	<0.0005
	Max	0.0520	0.056	0.0210	0.0050	0.0230	0.0740	0.0050	0.0050	0.0210	0.0430	0.0063	0.0050	0.0090	0.0360	0.0050
	No. Detected	89%	84%	84%	5%	79%	79%	47%	0%	74%	89%	58%	0%	42%	68%	0%
Urban industrial (*n* = 34)	Min	0.0006	0.0007	<0.0005	<0.001	<0.0005	<0.005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.001	<0.0005
	Max	0.0680	0.078	0.0360	0.0095	0.0160	0.0380	0.0160	0.0019	0.0380	0.5700	0.0140	0.0014	0.0063	0.0390	0.0013
	No. Detected	100%	100%	97%	15%	85%	79%	71%	3%	85%	94%	68%	3%	68%	88%	3%
Urban residential (*n* = 23)	Min	<0.0002	<0.0002	<0.0005	<0.001	<0.0005	<0.005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.001	<0.0005
	Max	0.0440	0.081	0.0290	0.0091	0.0061	0.0340	0.0210	0.0008	0.0280	0.0570	0.0035	0.0007	0.0054	0.0300	<0.0005
	No. Detected	100%	100%	100%	13%	100%	96%	83%	13%	91%	100%	74%	4%	52%	91%	0%


Legend
Matrix: water
Analyte: PFOS
Concentration range (ug/L)
Minimum <0.0002
Maximum 0.081
Median 0.0062
Count 104
% detected 87%
PFOS (ug/L)
<0.0002
0.0002 - 0.001
0.001 - 0.01
0.01 - 0.081
0.081 - 0.13
Landuse
Agricultural/Other
Commercial/Education
Hospital/Medical
Industrial
Parkland
Residential
Transport
Water
99% ANZG 0.00023 ug/L
95% ANZG 0.13 ug/L
0 30 60 90
km
N
Echuca
Benalla
Data: EPA (2019/2020), VicGov (2020), ABS (Census 2016), ESRI (2020)

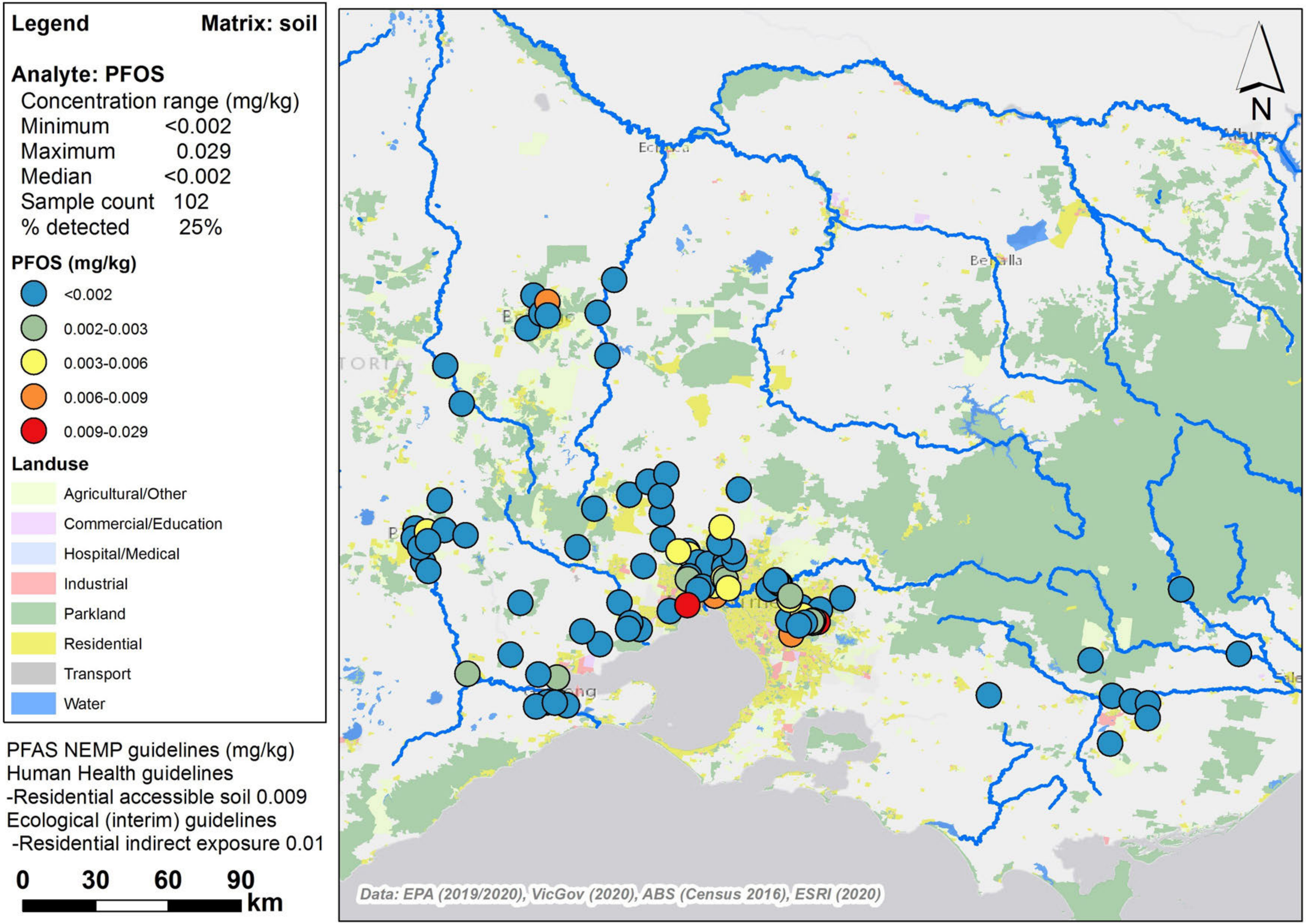
Supplementary Table 2B. PFAS concentrations and detection frequencies in sediments.

	Chemical	PFHxS	PFOS	PFOA	8:2 FTS	PFBS	PFBA	PFDS	PFDoDA	PFHpS	PFHxA	PFNA	PFPeS	PFPeA	PFTeDA
Guidelines	Units	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
Sediment guidelines for PFAS (NA)		NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	LORs	<0.001	<0.002	<0.001	<0.001	<0.001	<0.002	<0.001	<0.002	<0.001	<0.001	<0.001	<0.001	<0.002	<0.002
	Max	0.001	0.039	0.002	0.001	0.001	0.006	0.013	0.012	0.002	0.001	0.001	0.001	0.013	0.002
	Count	101	101	101	101	101	101	101	101	101	101	101	101	101	101
	Detects	2%	25%	1%	1%	1%	5%	11%	5%	1%	1%	1%	2%	3%	1%
Ambient Landuse	**Statistic**	**PFHxS**	**PFOS**	**PFOA**	**8:2 FTS**	**PFBS**	**PFBA**	**PFDS**	**PFDoDA**	**PFHpS**	**PFHxA**	**PFNA**	**PFPeS**	**PFPeA**	**PFTeDA**
Background (16)	Min	0.000	0.003	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.009	0.000
	Max	0.000	0.003	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.013	0.000
	Detects	0%	6%	0%	0%	0%	0%	6%	0%	0%	0%	0%	0%	13%	0%
High-intensity agriculture (10)	Min	0.001	0.002	0.000	0.000	0.001	0.000	0.001	0.000	0.000	0.000	0.000	0.001	0.000	0.000
	Max	0.001	0.005	0.000	0.000	0.001	0.000	0.001	0.000	0.000	0.000	0.000	0.001	0.000	0.000
	Detects	10%	20%	0%	0%	10%	0%	10%	0%	0%	0%	0%	10%	0%	0%
Low-intensity agriculture (19)	Min	0.000	0.002	0.000	0.000	0.000	0.003	0.000	0.002	0.000	0.000	0.000	0.001	0.000	0.000
	Max	0.000	0.005	0.000	0.000	0.000	0.006	0.000	0.002	0.000	0.000	0.000	0.001	0.000	0.000
	Detects	0%	16%	0%	0%	0%	11%	0%	5%	0%	0%	0%	5%	0%	0%
Urban industrial (31)	Min	0.001	0.002	0.000	0.001	0.000	0.003	0.001	0.002	0.000	0.000	0.000	0.000	0.000	0.002
	Max	0.001	0.008	0.000	0.001	0.000	0.003	0.005	0.007	0.000	0.000	0.000	0.000	0.000	0.002
	Detects	3%	42%	0%	3%	0%	6%	19%	10%	0%	0%	0%	0%	0%	3%
Urban residential (23)	Min	0.000	0.002	0.002	0.000	0.000	0.003	0.001	0.012	0.002	0.001	0.001	0.000	0.005	0.000
	Max	0.000	0.039	0.002	0.000	0.000	0.003	0.013	0.012	0.002	0.001	0.001	0.000	0.005	0.000
	Detects	0%	26%	4%	0%	0%	4%	13%	4%	4%	4%	4%	0%	4%	0%


Legend
Matrix: sediment
Analyte: PFOS
Concentration range (mg/kg)
Minimum <0.002
Maximum 0.039
Median <0.002
Sample count 101
% detected 25%
PFOS (mg/kg)
<0.002
0.002-0.003
0.003-0.006
0.006-0.009
0.009-0.039
Landuse
Agricultural/Other
Commercial/Education
Hospital/Medical
Industrial
Parkland
Residential
Transport
Water
*currently no guideline values for sediments
0 30 60 90
km
N
Benalla
Data: EPA (2019/2020), VicGov (2020), ABS (Census 2016), ESRI (2020)

Supplementary Table 2C. PFAS concentrations and detection ferquency in soils.

	Compound	PFHxS	PFOS	PFOA	NEtFOSAA	PFBS	PFBA	PFDS	PFDoDA	PFHpA	PFHxA	PFNA	PFOSA	PFPeS	PFPeA	PFUnDA
	Units	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
Guidelines																
PFAS NEMP Human Health - Commercial industrial		20	20	50	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
PFAS NEMP Human Health - Public open space		0	1	10	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
PFAS NEMP Human Health - Residential accessible soil		0.009	0.009	0.1	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
PFAS NEMP Human Health - Residential miniumum accessible soil		2	2	20	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
PFAS NEMP Ecological - Public open space direct exposure (interim)		1	1	10	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
PFAS NEMP Ecological - Commercial industrial indirect exposure (interim)		NA	0.14	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
PFAS NEMP Ecological - Residential indirect exposure (interim)		NA	0.01	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	LORs	<0.001	<0.002	<0.001	<0.002	<0.001	<0.002	<0.001	<0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.002	<0.002
	Maximum	0.0011	0.029	0	0.012	0	0	0.0016	0	0.0045	0	0	0.0028	0	0.023	0
	Count	106	106	106	106	106	106	106	106	106	106	106	106	106	106	106
	Detects	1%	25%	0%	1%	0%	0%	2%	0%	1%	0%	0%	1%	0%	7%	0%
Ambient Landuse	**Statistic**															
Background (n = 18)	Min	<0.001	<0.002	<0.001	<0.002	<0.001	<0.002	<0.001	<0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.002	<0.002
	Max	0	0.016	0	0	0	0	0	0	0	0	0	0	0	0.0044	0
	Detects	0%	6%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	6%	0%
High-intensity agriculture (n = 10)	Min	<0.001	<0.002	<0.001	<0.002	<0.001	<0.002	<0.001	<0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.002	<0.002
	Max	0	0.0027	0	0	0	0	0	0	0	0	0	0	0	0.008	0
	Detects	0%	10%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	10%	0%
Low-intensity agriculture (n = 19)	Min	<0.001	<0.002	<0.001	<0.002	<0.001	<0.002	<0.001	<0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.002	<0.002
	Max	0	0.0037	0	0	0	0	0	0	0	0	0	0	0	0.023	0
	Detects	0%	21%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	16%	0%
Urban industrial (n = 35)	Min	<0.001	<0.002	<0.001	<0.002	<0.001	<0.002	<0.001	<0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.002	<0.002
	Max	0.0011	0.029	0	0	0	0	0.0016	0	0	0	0	0	0	0.012	0
	Detects	100%	34%	0%	0%	0%	0%	8%	0%	0%	0%	0%	0%	0%	3%	0%
Urban residential (n = 24)	Min	<0.001	<0.002	<0.001	<0.002	<0.001	<0.002	<0.001	<0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.002	<0.002
	Max	0	0.0068	0	0.012	0	0	0	0	0.0045	0	0	0.0028	0	0.0052	0
	Detects	0%	33%	0%	4%	0%	0%	0%	0%	4%	0%	0%	4%	0%	4%	0%


Legend
Matrix: soil
Analyte: PFOS
Concentration range (mg/kg)
Minimum <0.002
Maximum 0.029
Median <0.002
Sample count 102
% detected 25%
PFOS (mg/kg)
<0.002
0.002-0.003
0.003-0.006
0.006-0.009
0.009-0.029
Landuse
Agricultural/Other
Commercial/Education
Hospital/Medical
Industrial
Parkland
Residential
Transport
Water
PFAS NEMP guidelines (mg/kg)
Human Health guidelines
-Residential accessible soil 0.009
Ecological (interim) guidelines
-Residential indirect exposure 0.01
0 30 60 90
km
N
Data: EPA (2019/2020), VicGov (2020), ABS (Census 2016), ESRI (2020)

Supplementary Table 2D. Concentrations and detection frequency of PFAS in site-specific soil.

Compound	PFBA	PFHpA	PFHpS	PFHxS	PFNS	PFOA	PFOS	PFPeA
Guidelines								
PFAS NEMP Human Health - Commercial industrial	NA	NA	NA	20	NA	50	20	NA
PFAS NEMP Human Health - Public open space	NA	NA	NA	0	NA	10	1	NA
PFAS NEMP Human Health - Residential accessible soil	NA	NA	NA	0 009	NA	0.1	0.009	NA
PFAS NEMP Human Health - Residential miniumum accessible soil	NA	NA	NA	2	NA	20	2	NA
PFAS NEMP Ecological - Public open space direct exposure (interim)	NA	NA	NA	1	NA	10	1	NA
PFAS NEMP Ecological - Commercial industrial indirect exposure (interim)	NA	NA	NA	NA	NA	NA	0.14	NA
PFAS NEMP Ecological - Residential indirect exposure (interim)	NA	NA	NA	NA	NA	NA	0.01	NA
LORs	<0.002	<0 001	<0 001	<0 001	<0 001	<0.001	<0.002	<0.002
Maximum	0.0051	0.0019	0.035	0	0.0058	0	0.0094	0 024
Count	3	1	1	0	1	0	12	4
Detects	2%	1%	1%	0%	1%	0%	8%	3%

Site-specific	Count	PFBA Detects (%)	PFBA Max (mg/kg)	PFHpA Detects (%)	PFHpA Max (mg/kg)	PFHpS Detects (%)	PFHpS Max (mg/kg)	PFHxS Detects (%)	PFHxS Max (mg/kg)	PFNS Detects (%)	PFNS Max (mg/kg)	PFOA Detects (%)	PFOA Max (mg/kg)	PFOS Detects (%)	PFOS Max (mg/kg)	PFPeA Detects (%)	PFPeA Max (mg/kg)
Ballarat (Buninyong)	7	0	0	0	0	14	0.035	0	0	14	0.0058	0	0	0	0	0	0
Bendigo (Kyabram, Campaspe)	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bendigo2 (Nanneella, Campaspe)	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bendigo3 (Nagambie, Strathbogie)	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	0.024
Bendigo4 (Bailieston, Strathbogie)	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bendigo5 (Heathcote)	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bendigo6 (Dunolly)	8	13	0.0051	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bendigo7 (EagleHawk)	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bendigo8 (Axedale)	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Brimbank (Sunshine North)	15	0	0	0	0	0	0	0	0	0	0	0	0	47	0.0038	0	0
Geelong (Waurn Ponds)	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hume (Campbellfield)	15	7	0.003	0	0	0	0	0	0	0	0	0	0	27	0.0051	0	0
Latrobe (Yallourn North)	10	20	0.0026	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Macedon (Monegeetta)	5	0	0	0	0	0	0	0	0	0	0	0	0	60	0 0094	0	0
Manningham (Doncaster East)	15	0	0	7	0.0019	0	0	0	0	0	0	0	0	27	0.0045	20	0 011
Otways (Gherang)	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Supplementary Table 3A. Concentration and detection frequency of pesticides in water.

	Chemical	Atrazine	Bifenthrin	Diuron	Hexazinone	Iprodione	Metolachlor	Piperonyl Butoxide	Propargite	Pyrimethanil	Simazine	Tebuthiuron	Tebuconazole
	Units	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
Drinking Water (Health)		20	NA	20	NA	400	300	NA	7	NA	20	NA	NA
Recreational Water (Health)		200	NA	200	NA	4000	3000	NA	70	NA	200	NA	NA
Environmental (99% level)		0.7	NA	NA	NA	NA	NA	NA	NA	NA	0.2	0.02	0.02
Environmental (95% level)		13	NA	NA	NA	NA	NA	NA	NA	NA	3.2	2.2	2 2
Environmental (90% level)		45	NA	NA	NA	NA	NA	NA	NA	NA	11	20	20
	LORs	<0.01	<0.005	<0.01	<0.01	<0.01	<0.1	<0.01	<0.01	<0.01	<0.01	<1	<0.01
	Max	0 91	0.014	0.16	0.24	0.078	0.13	0.028	0.024	0.37	1.3	1.42	0.078
	Count	103	103	103	103	103	103	103	103	103	103	103	103
	Detects	15%	6%	21%	8%	1%	1%	3%	1%	1%	45%	1%	6%
Ambient Landuse													
Background (16)	Min	<0.01	<0.005	<0.01	<0.01	<0.01	<0.1	<0.01	<0.01	<0.01	<0.01	<1	<0.01
	Max	0.03	0	0	0.13	0	0	0	0	0	0.05	0	0
	Detects	6%	0%	0%	6%	0%	0%	0%	0%	0%	6%	0%	0%
High-intensity agriculture (11)	Min	<0.01	<0.005	<0.01	<0.01	<0.01	<0.1	<0.01	<0.01	<0.01	<0.01	<1	<0.01
	Max	0.10	0.01	0.08	0.19	0.08	0.00	0.00	0	0.37	0.18	0	0.00
	Detects	40%	10%	20%	10%	10%	0%	0%	0%	10%	40%	0%	0%
Low-intensity agriculture (19)	Min	<0.01	<0.005	<0.01	<0.01	<0.01	<0.1	<0.01	<0.01	<0.01	<0.01	<1	<0.01
	Max	0.91	0	0	0.20	0.00	0.13	0.00	0.00	0.00	0.31	0	0.00
	Detects	21%	0%	0%	11%	0%	5%	0%	0%	0%	37%	0%	0%
Urban industrial (34)	Min	<0.01	<0.005	<0.01	<0.01	<0.01	<0.1	<0.01	<0.01	<0.01	<0.01	<1	<0.01
	Max	0.28	0.01	0.09	0.24	0	0	0.03	0	0	1.3	0	0.08
	Detects	15%	9%	32%	12%	0%	0%	6%	0%	0%	68%	0%	12%
Urban residential (23)	Min	<0.01	<0.005	<0.01	<0.01	<0.01	<0.1	<0.01	<0.01	<0.01	<0.01	<1	<0.01
	Max	0.06	0.01	0.16	0	0	0	0.03	0.02	0	0.32	1.42	0.035
	Detects	4%	9%	35%	0%	0%	0%	4%	4%	0%	48%	4%	9%

Supplementary Table 3B. Concentration and detection frequency of pesticides in sediments.

	Compound	Aldrin	Bifenthrin	Chlordane (cis)	Chlordane (trans)	DDE	DDD	DDT	Dieldrin	Pyrimethanil
	Units	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg
Guidelines										
ANZG (2018) Sediment Quality Guideline Value#		NA	NA	NA	NA	1.4	3.5	1.2	2.8	NA
ANZG (2018) Sediment Quality Guideline High#		NA	NA	NA	NA	7	9	5	7	NA
	LORs	<1	<1	<1	<1	<1	<1	<1	<1	<1
	Max	12	79	1.6	3.6	170	12	200	18	76
	Count	97	97	97	97	97	97	97	97	97
	Detects	1%	34%	3%	7%	20%	10%	8%	26%	1%
Ambient Landuse										
Background (16)	Min	<1	<1	<1	<1	<1	<1	<1	<1	<1
	Max	<1	4.6	<1	0	11	8.5	40	1.5	<1
	%Detected	0%	6%	0%	0%	6%	6%	6%	6%	0%
High-intensity agriculture (10)	Min	<1	<1	<1	<1	<1	<1	<1	<1	<1
	Max	<1	<1	<1	<1	170	12	200	3.8	76
	%Detected	0%	0%	0%	0%	20%	10%	10%	20%	10%
Low-intensity agriculture (18)	Min	<1	<1	<1	<1	<1	<1	<1	<1	<1
	Max	<1	71	<1	<1	<1	<1	<1	8.2	<1
	%Detected	0%	22%	0%	0%	0%	0%	0%	17%	0%
Urban industrial (31)	Min	<1	<1	<1	<1	<1	<1	<1	<1	<1
	Max	<1	79	1.6	2.1	3.2	1.6	2.7	<1	<1
	%Detected	0%	42%	6%	10%	26%	6%	10%	23%	0%
Urban residential (22)	Min	<1	<1	<1	<1	<1	<1	<1	<1	<1
	Max	12	44	<1	3.6	16	3.2	2	18	<1
	%Detected	5%	68%	5%	14%	36%	27%	14%	55%	0%

Guideline values not corrected for organic carbon

Supplementary Table 4A. Phthalate concentrations in water samples across all landuse types.

	Compound	Bis(2-ethylhexyl) phthalate	Di-n-butyl phthalate	Diethylphthalate	Dimethyl phthalate
Guidelines	**Units**	µg/L	µg/L	µg/L	µg/L
Drinking Water (Health)		10	NA	NA	NA
Recreational Water (Health)		100	NA	NA	NA
Environmental (99% level)		NA	9.9	900	3,000
Environmental (95% level)		NA	26	1000	3,700
Environmental (90% level)		NA	40.2	1,100	4,300
	LORs	<3	<9	<10	<10
	Max	<3	<9	<10	<10
	Count	112	112	112	112
	Detects	1%	0%	0%	0%
Sample results	**Landuse**				
Blind Ck at Blind Ck Trail	Urban Residential	6.4	<9	<10	<10

Supplementary Table 4B. Phthalate concentrations detected in sediments.

Guidelines	Compound	Bis(2-ethylhexyl) phthalate	Butyl benzyl phthalate	Di-n-butyl phthalate	Di-n-octyl phthalate	Diethylphthalate	Dimethyl phthalate
	Units	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
Sediment guidelines for Phthalates (NA)		NA	NA	NA	NA	NA	NA
	LORs	<0.1	<1	<1	<1	<1	<1
	Max	15	1.2	<1	<1	<1	<1
	Count	102	102	102	102	102	102
	Detects	25%	3%	0%	0%	0%	0%
Standards	**Land-use**						
Edgards Ck at Rockfield St	Low-intensity agriculture	2.2	<1	<1	<1	<1	<1
Moonee Ponds Ck at Moonee Ponds Ck Trail	Low-intensity agriculture	0.83	<1	<1	<1	<1	<1
Moonee Ponds Ck at Moonee Ponds Ck Trail	Low-intensity agriculture	0.71	<1	<1	<1	<1	<1
Moonee Ponds Ck at Mickleham Rd	Low-intensity agriculture	1.9	<1	<1	<1	<1	<1
Bonshaw Ck at Royale St	Urban Industrial	1.4	<1	<1	<1	<1	<1
Merri Ck at Merri Ck Trail	Urban Industrial	2.6	<1	<1	<1	<1	<1
Merri Ck at Mahoneys Rd	Urban Industrial	8.3	<1	<1	<1	<1	<1
Merri Ck at Carr St	Urban Industrial	5.7	<1	<1	<1	<1	<1
Edgards Ck at Deveny Rd	Urban Industrial	1.5	<1	<1	<1	<1	<1
Merri Ck at Murray Rd	Urban Industrial	0.92	<1	<1	<1	<1	<1
Hume Replicate	Urban Industrial	15	1.2	<1	<1	<1	<1
Dandenong Ck at Marlborough Rd	Urban Industrial	1.4	<1	<1	<1	<1	<1
Corhanwarrabul Ck at Taldra Dr	Urban Industrial	0.51	<1	<1	<1	<1	<1
Knox2 Replicate	Urban Industrial	0.49	<1	<1	<1	<1	<1
Laverton Ck at Old Geelong Rd	Urban Industrial	1.2	<1	<1	<1	<1	<1
Moonee Ponds Ck at Macalay Rd	Urban Industrial	1.9	<1	<1	<1	<1	<1
Canadian Ck at Hocking Ave	Urban Residential	1.8	<1	<1	<1	<1	<1
Bendigo Ck at Wesley St	Urban Residential	1.5	<1	<1	<1	<1	<1
Waurn Ponds Ck at Torquad Road	Urban Residential	1.1	<1	<1	<1	<1	<1
Blind Ck at Scoresby Rd	Urban Residential	0.87	1.2	<1	<1	<1	<1
Blind Ck at Blind Ck Trail	Urban Residential	<1	1.2	<1	<1	<1	<1
Dandenong Ck at Illawarra Ave	Urban Residential	5.7	<1	<1	<1	<1	<1
Knox1 Replicate	Urban Residential	0.68	<1	<1	<1	<1	<1
Traralgon Ck at Peterkin St	Urban Residential	1.9	<1	<1	<1	<1	<1
Ruffeys Ck at The Boulevarde	Urban Residential	1.5	<1	<1	<1	<1	<1
Lollipop Ck at Honour Ave	Urban Residential	1.3	<1	<1	<1	<1	<1
Yuroke Ck at Dimboola Rd	Urban Residential	1.9	<1	<1	<1	<1	<1

Supplementary Table 4C. Phthalate concentrations detected in soils.

	Compound	Bis(2-ethylhexyl) phthalate	Butyl benzyl phthalate	Di-n-butyl phthalate	Di-n-octyl phthalate	Diethylphthalate	Dimethyl phthalate
	Units	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
Guidelines							
Soil guidelines for Phthalates (NA)		NA	NA	NA	NA	NA	NA
	LORs	<0.1	<1	<1	<1	<1	<1
	Max	2.9	<1	<1	<1	<1	<1
	Count	101	101	101	101	101	101
	Detects	11%	0%	0%	0%	0%	0%
Standards	Land-use	Bis(2-ethylhexyl) phthalate	Butyl benzyl phthalate	Di-n-butyl phthalate	Di-n-octyl phthalate	Diethylphthalate	Dimethyl phthalate
Bendigo Ck d/s Howard St	Urban Industrial	0.73	<1	<1	<1	<1	<1
Waurn Ponds Ck at Cochranes Rd	Urban Industrial	0.39	<1	<1	<1	<1	<1
Merri Ck at Carr St	Urban Industrial	0.38	<1	<1	<1	<1	<1
Merri Ck at Murray Rd	Urban Industrial	0.47	<1	<1	<1	<1	<1
Kororoit Ck at Blackshaw Rd	Urban Industrial	1.2	<1	<1	<1	<1	<1
Wyndam Replicate	Urban Industrial	0.95	<1	<1	<1	<1	<1
Moonee Ponds Ck at Macalay Rd	Urban Industrial	0.94	<1	<1	<1	<1	<1
Merri Ck u/s Arthurton Rd	Urban Residential	1.2	<1	<1	<1	<1	<1
Ferny Ck d/s Brenock Park Dr	Urban Residential	0.43	<1	<1	<1	<1	<1
Knox2 Replicate	Urban Residential	0.61	<1	<1	<1	<1	<1
Lollipop Ck at Honour Ave	Urban Residential	2.9	<1	<1	<1	<1	<1

Supplementary Table 5A. Concentrations and detection frequency of metals in water samples.

	Element	Aluminium	Antimony	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium	Cobalt	Copper	Iron	Lead	Lithium	Manganese	Mercury	Molybdenum	Nickel	Selenium	Strontium	Thallium	Tin	Vanadium	Zinc
	Units	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Guidelines																								
Drinking Water (Health)		NA	0.003	0.01	2	0.06	4	0.002	NA	NA	2	NA	0.01	NA	0.5	0.001	0.05	0.02	0.01	NA	NA	NA	NA	NA
Recreational Water (Health)		NA	0.03	0.1	20	0.6	40	0.02	NA	NA	20	NA	0.1	NA	5	0.01	0.5	0.2	0.1	NA	NA	NA	NA	NA
Environmental (99% level)		0.027	NA	0.0008	NA	NA	0.09	0.00006	0.00001	NA	0.001	NA	0.001	NA	1.2	0.00006	NA	0.008	0.005	NA	NA	NA	NA	0.0024
Environmental (95% level)		0.055	NA	0.024	NA	NA	0.37	0.0002	0.0004	NA	0.0014	NA	0.0034	NA	1.9	0.0006	NA	0.011	0.011	NA	NA	NA	NA	0.008
Environmental (90% level)		0.08	NA	0.094	NA	NA	0.68	0.0004	0.0018	NA	0.0018	NA	0.0056	NA	2.5	0.0019	NA	0.013	0.018	NA	NA	NA	NA	0.015
Environmental (Unknown level)#		8.00E-04	0.009	NA	NA	NA	NA	NA	0.0033	NA	NA	NA	NA	NA	NA	NA	0.034	NA	NA	NA	0.00003	NA	0.006	NA
	Min	<0.005	<0.001	<0.001	<0.001	<0.001	<0.005	<0.0001	<0.001	<0.001	<0.001	<0.005	<0.001	<0.001	<0.001	<0.0001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	Max	10.2	0.0025	0.058	0.23	0	2.3	0.00063	0.013	0.0062	0.0072	12.3	0.0083	0.083	0.59	0.00011	0.01	0.017	0.0016	4.4	0.0013	0	0.04	0.13
	Detects	98%	4%	66%	99%	0%	91%	5%	29%	15%	74%	100%	16%	87%	98%	1%	27%	84%	2%	99%	2%	0%	71%	83%
Landuse																								
Background (17)	Min	<0.005	<0.001	<0.001	<0.001	<0.001	<0.005	<0.0001	<0.001	<0.001	<0.001	<0.005	<0.001	<0.001	<0.001	<0.0001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	Max	10.2	0.0017	0.016	0.2	0	0.19	**0.00063**	0.013	0.002	0.0072	12.3	0.0083	0.0071	0.083	0.00011	0	0.017	0	1.37	0	0	0.023	0.018
	%Detected	17	1	11	17	0	14	1	4	2	8	17	3	12	17	1	0	9	0	17	0	0	7	11
High-intensity agriculture (10)	Min	<0.005	<0.001	<0.001	<0.001	<0.001	<0.005	<0.0001	<0.001	<0.001	<0.001	<0.005	<0.001	<0.001	<0.001	<0.0001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	Max	2.67	0	0.025	0.13	0	0.056	0	0.0041	0.0023	0.0039	3.71	0.0023	0.0083	0.15	0	0	0.0076	0	0.49	0	0	0.0061	0.006
	%Detected	10	0	7	10	0	7	0	6	2	6	10	2	7	10	0	0	10	0	10	0	0	9	9
Low-intensity agriculture (19)	Min	<0.005	<0.001	<0.001	<0.001	<0.001	<0.005	<0.0001	<0.001	<0.001	<0.001	<0.005	<0.001	<0.001	<0.001	<0.0001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	Max	2.16	0	0.017	0.14	0	0.21	0	0.0021	0.0024	0.0049	3.3	0.007	0.029	0.59	0	0.0033	0.0093	0.001	0.63	0	0	0.0055	0.021
	%Detected	19	0	11	19	0	19	0	5	4	13	19	1	17	19	0	8	17	1	19	0	0	15	12
Urban industrial (34)	Min	<0.005	<0.001	<0.001	<0.001	<0.001	<0.005	<0.0001	<0.001	<0.001	<0.001	<0.005	<0.001	<0.001	<0.001	<0.0001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	Max	7.08	0.0015	0.058	0.23	0	2.3	0.00026	0.013	0.0062	0.0049	9.37	0.0063	0.083	0.43	0	0.0063	0.016	0.0016	4.4	0.0013	0	0.04	0.081
	%Detected	33	1	20	34	0	32	2	7	4	30	34	4	33	33	0	15	31	1	34	2	0	27	32
Urban residential (23)	Min	<0.005	<0.001	<0.001	<0.001	<0.001	<0.005	<0.0001	<0.001	<0.001	<0.001	<0.005	<0.001	<0.001	<0.001	<0.0001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	Max	2.7	0.0025	0.0086	0.083	0	0.29	0.00029	0.0043	0.0014	0.007	4.87	0.0039	0.012	0.16	0	0.01	0.006	0	0.82	0	0	0.0092	0.13
	%Detected	22	2	19	22	0	22	2	8	3	19	22	6	21	22	0	5	20	0	22	0	0	15	21

#Unknown level of species protection; low-reliability guideline value (ANZG 2018)

Supplementary Table 5B. Concentrations of metals in sediment samples and detection frequency.

	Compound	Aluminium	Antimony	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium	Cobalt	Copper	Iron	Lead	Lithium	Manganese	Mercury	Molybdenum	Nickel	Selenium	Strontium	Thallium	Tin	Vanadium	Zinc
	Units	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
ADWG (2018) Sediment Quality Guideline Value		NA	2	20	NA	NA	NA	1.5	80	NA	65	NA	50	NA	NA	0.15	NA	21	NA	NA	NA	NA	NA	200
ADWG (2018) Sediment Quality Guideline High		NA	25	70	NA	NA	NA	10	370	NA	270	NA	220	NA	NA	1	NA	52	NA	NA	NA	NA	NA	410
	LORs	<5	<0.5	<0.5	<0.5	<0.5	<1	<0.5	<0.5	<0.5	<0.5	<5	<0.5	<0.5	<0.5	<0.2	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
	Max	33600	4.3	97	550	3	19	0.85	120	110	130	93900	240	35	3060	0.37	2.9	160	5.1	140	0	72	160	1420
	Count	101	101	101	101	101	101	101	101	101	101	101	101	101	101	101	101	101	101	101	101	101	101	101
	Detects	100	51	100	101	69	72	6	101	101	101	101	101	101	101	7	44	101	31	101	0	86	101	101
Landuse	**Statistic**	**Aluminium**	**Antimony**	**Arsenic**	**Barium**	**Beryllium**	**Boron**	**Cadmium**	**Chromium**	**Cobalt**	**Copper**	**Iron**	**Lead**	**Lithium**	**Manganese**	**Mercury**	**Molybdenum**	**Nickel**	**Selenium**	**Strontium**	**Thallium**	**Tin**	**Vanadium**	**Zinc**
Background (18)	Min	<5	<0.5	<0.5	<0.5	<0.5	<1	<0.5	<0.5	<0.5	<0.5	<5	<0.5	<0.5	<0.5	<0.2	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
	Max	27,500	2.8	97	550	3	4.4	0.25	44	43	29	80,100	20	17	1,170	0.1	2.4	65	1.1	94	0.25	2.7	100	110
	Detects	0%	50%	94%	0%	0%	0%	0%	100%	0%	100%	0%	100%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	100%
High-intensity agriculture (10)	Min	<5	<0.5	<0.5	<0.5	<0.5	<1	<0.5	<0.5	<0.5	<0.5	<5	<0.5	<0.5	<0.5	<0.2	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
	Max	32,500	0.89	20	450	1.5	9.8	0.25	120	110	76	62,900	47	15	3,060	0.1	1.3	39	0.63	89	0.25	5.8	110	340
	Detects	0%	10%	100%	0%	0%	0%	0%	100%	0%	100%	0%	100%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	100%
Low-intensity agriculture (19)	Min	<5	<0.5	<0.5	<0.5	<0.5	<1	<0.5	<0.5	<0.5	<0.5	<5	<0.5	<0.5	<0.5	<0.2	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
	Max	23,300	1.5	27	220	1.2	10	0.25	120	21	77	72,200	88	11	1,250	0.1	1.6	67	1.7	72	0.25	6.1	160	400
	Detects	0%	37%	100%	0%	0%	0%	0%	100%	0%	100%	0%	100%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	100%
Urban industrial (31)	Min	<5	<0.5	<0.5	<0.5	<0.5	<1	<0.5	<0.5	<0.5	<0.5	<5	<0.5	<0.5	<0.5	<0.2	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
	Max	33,600	4.3	69	330	2.9	19	0.85	100	51	130	93,900	240	35	1,220	0.37	2.9	160	5.1	140	0.25	23	130	1,420
	Detects	0%	58%	100%	0%	0%	0%	16%	100%	0%	100%	0%	100%	0%	0%	16%	0%	100%	0%	0%	0%	0%	0%	100%
Urban residential (23)	Min	<5	<0.5	<0.5	<0.5	<0.5	<1	<0.5	<0.5	<0.5	<0.5	<5	<0.5	<0.5	<0.5	<0.2	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
	Max	21,100	3.3	58	220	1.1	11	0.55	100	24	110	34,900	140	16	1,610	0.29	2.4	67	1.7	80	0.25	72	64	770
	Detects	0%	70%	100%	0%	0%	0%	4%	100%	0%	100%	0%	100%	0%	0%	9%	0%	100%	0%	0%	0%	0%	0%	100%