Australian National University

PFAS HEALTH STUDY

PFAS Health Study

Component two: Blood serum study of PFAS exposure, related risk factors and biochemical markers of health

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Contents

Acknowledgements ii
Contents iv
Plain language summary vii
Technical summary viii
Background viii
Methods viii
Results ix
Conclusion x
Abbreviations xi
Introduction 1
PFAS overview 1
Human health effects 2
PFAS contamination in Australia 3
PFAS Health Study 4
Blood Serum Study 5
Methods 7
Study design and recruitment 7
Data collection and measurement 8
Reporting 10
Data analysis 10
Ethical considerations 17
Results 20
Participation in the Blood Serum Study 20
Serum PFAS concentrations in Katherine, Oakey and Williamtown 23
Comparing serum PFAS concentrations in the exposed and comparison communities 30
Risk factors for elevated serum PFAS concentrations 36
Biochemical markers of health 44
Discussion 53
Serum PFAS concentrations in Katherine, Oakey and Williamtown 53
Risk factors for elevated serum PFAS concentrations 56
Biochemical markers of health 57

Study strengths and limitations 59
Conclusion 61
Glossary 63
Appendix 1 66
Biomarker reference ranges 66
Appendix 2 68
Participation in the Blood Serum Study 68
Appendix 3 70
Serum PFAS concentrations 70
Appendix 4 76
Serum PFAS concentrations in Alice Springs, Dalby and Kiama and Shellharbour 76
Comparing serum PFAS concentrations in the exposed and comparison communities 78
Appendix 5 79
Elevated serum PFAS concentrations 79
Risk factor sensitivity analysis 1: elevated PFAS level definition 79
Risk factor sensitivity analysis 2: exclusion of participants who have not lived in a PFAS Management Area in the past 5, 10 and 15 years 83
Risk factor sensitivity analysis 3: exclusion of participants who have not lived in a PFAS Management Area for at least one year 87
Risk factor sensitivity analysis 4: inclusion of PFAS elimination pathways 89
Risk factor sensitivity analysis 5: inclusion of all types of bore water exposure 91
Risk factor secondary analysis: continuous serum PFAS concentrations 93
Appendix 6 95
Biochemical markers 95
Biochemical marker sensitivity analysis 1: adjustment for additional potential confounders that arise if kidney function is assumed to affect PFAS serum concentrations, including eGFR, smoking status and alcohol consumption 97
Biochemical marker sensitivity analysis 2: exclusion of exposed participants who now live in comparison communities 103
Biochemical marker sensitivity analysis 3: exclusion of exposed participants who have not lived in the exposed communities in the last 15 years 109
Biochemical marker sensitivity analysis 4: exclusion of exposed participants who have not lived in the exposed communities in the last 10 years 115
Biochemical marker sensitivity analysis 5: exclusion of exposed participants who have not lived in the exposed communities in the last 5 years 121

Biochemical marker sensitivity analysis 6: exclusion of exposed participants who have not lived in the exposed communities in the last 10 years and past workers 127

Biochemical marker sensitivity analysis 7: exclusion of participants who have not lived in a PFAS Management Area for at least 1 year 133

Biochemical marker sensitivity analysis 8: PFAS serum concentrations below the limit of quantification imputed using multiple imputation by chained equations, rather than using a single plug-in value 139

Biochemical marker sensitivity analysis 9: missing values in confounding variables imputed using multiple imputation by chained equations 145

Biochemical marker sensitivity analysis 10: exclusion of participants diagnosed with comorbidities in last 5 years 151

Biochemical marker sensitivity analysis 11: exclusion of participants with declining kidney function (eGFR <60) 158

Biochemical marker analysis: comparison communities 163

References 171

Plain language summary

Per- and polyfluoroalkyl substances (PFAS) are man-made chemicals that may be harmful to human health. The main goal of the Blood Serum Study was to see whether people who lived or worked in Australian communities affected by PFAS contamination had higher levels of PFAS in their blood. The three communities were Katherine in the Northern Territory (NT), Oakey in Queensland (Qld) and Williamtown in New South Wales (NSW) — the 'exposed communities'. To do this, we compared blood levels of PFAS in people from the exposed communities to blood levels of PFAS in people in who lived in similar communities without environmental PFAS contamination. The three communities without contamination were Alice Springs in the NT, Dalby in Qld, and Kiama and Shellharbour in NSW — the 'comparison communities'.

From 2016 to 2020, people from the exposed and comparison communities provided a blood sample for PFAS testing and completed a questionnaire. A medical laboratory measured the levels of nine types of PFAS in blood. Only perfluorooctane sulfonic acid (PFOS), perfluorohexane sulfonic acid (PFHxS) and perfluorooctanoic acid (PFOA) were detected in more than 80% of all blood samples.

Average (geometric mean) PFAS levels of participants from the exposed communities were higher than participants from the comparison communities. Although, PFOA levels were similar in the exposed and comparison communities. Across the three exposed communities, the average PFAS levels in blood ranged from 4.9 to 6.6 nanograms per millilitre (ng/mL) for PFOS, from 2.9 to 3.7 ng/mL for PFHxS and from 1.3 to 1.8 ng/mL for PFOA. Across the three comparison communities, the PFAS levels in blood ranged from 2.5 to 3.3 ng/mL for PFOS, from 0.7 to 1.2 ng/mL for PFHxS and from 1.2 to 1.4 ng/mL for PFOA. PFOS and PFHxS were the main ingredients of the firefighting foams that contaminated the environment of the exposed communities.

About half of participants from the exposed communities had high blood levels of PFHxS. About a third had high blood levels of PFOS. We investigated what may have led to participants who lived in the exposed communities having high levels of PFAS in their blood. We identified several risk factors for a person having a high blood level of PFOS or PFHxS in their blood, including consuming bore water or certain locally grown foods, living in an exposed community for a long period of time and exposure to firefighting foams in the workplace. Most participants from the exposed communities reported that they changed how much they used bore water or ate locally grown foods once they knew about the PFAS contamination.

A medical laboratory also measured different chemicals related to health (biochemical markers) in blood samples, such as cholesterol, so we could see how they vary with PFAS levels in blood. Overall, there were few instances where higher PFAS levels were associated with higher or lower levels of biochemical markers. One example was that participants from Williamtown who had higher PFOS, PFHxS or PFOA levels in their blood also had a higher level of cholesterol in their blood. Higher levels of cholesterol in blood may lead to blockages in the coronary arteries, the blood vessels that carry oxygen into the heart muscle. Another example was for blood tests related to kidney function. Participants from Katherine and Williamtown who had higher PFAS levels in their blood also had higher levels of uric acid in their blood. All of these differences in biochemical markers were small and unlikely to lead to poor health. Further, higher PFAS levels in blood may not be the causes of the differences in biochemical markers but the consequences of them. For example, someone with poor kidney function may not be able to excrete PFAS from their body as easily as someone with normal kidney function, which may result in higher PFAS levels in blood.

Blood levels of PFAS in the exposed communities were similar to those in some communities in the United States of America affected by environmental PFAS contamination from firefighting foams, but lower than in a community in Sweden. Consuming bore water or certain locally grown foods were risk factors for high levels of PFAS in blood. Changes in behaviour could limit people's intake of PFAS and blood levels for most people will decline naturally over time.

Technical summary

Background

Per- and polyfluoroalkyl substances (PFAS) are synthetic chemicals classified as contaminants of emerging concern due to their potential to adversely affect the environment and human health. From 2013 to 2017, the Australian Government identified PFAS contamination affecting the local environments surrounding the Royal Australian Air Force Bases at Tindal in Katherine, Northern Territory (NT) and Williamtown, New South Wales (NSW), and the Army Aviation Centre in Oakey, Queensland (Qld), which are referred to as PFAS Management Areas.

The primary aim of the Blood Serum Study was to determine whether people who had lived or worked in the PFAS Management Areas (the 'exposed communities') had higher blood serum PFAS concentrations than people living in other Australian communities not affected by environmental PFAS contamination (the 'comparison communities'). Secondary aims of the Blood Serum Study were to identify risk factors for elevated (higher than background) blood serum PFAS concentrations in residents of the exposed communities and to assess the cross-sectional associations between serum PFAS concentrations and biochemical markers of health, including kidney, liver and thyroid function and lipid (e.g., cholesterol) levels.

Methods

From 2016 to 2019, the Australian Government conducted the Voluntary Blood Testing Program (VBTP) for PFAS where people who had lived or worked in the exposed communities could have their blood tested for PFAS. We recruited VBTP participants into the Blood Serum Study and the Cross-sectional Survey; these participants formed the sample for the exposed communities. The Cross-sectional Survey collected data on participants' PFAS exposure history, physical and mental health, and sociodemographic characteristics. At the time of participation in the Cross-sectional Survey, participants were asked whether they consented to having their blood sample tested for biochemical markers of health.

We chose three comparison communities that were similar to the exposed communities in terms of area-level sociodemographic characteristics, including socioeconomic status, remoteness and the proportion of residents who identified as an Aboriginal and/or Torres Strait Islander person. The comparison communities were Alice Springs in the NT, Dalby in Qld, and Kiama and Shellharbour in NSW. Services Australia randomly sampled 30,000 adult residents (10,000 from each community) from the Australian Government Medicare Enrolment File and sent them an invitation to participate in the PFAS Health Study on behalf of the Australian National University study team. At the time of recruitment, adults from the comparison communities were invited to participate in the Blood Serum Study and Cross-sectional Survey.

A single pathology company — Sonic Healthcare — conducted all blood tests for the Blood Serum Study. Sonic Healthcare measured the concentrations of nine PFAS in duplicate blood serum samples from each participant using Liquid Chromatography Tandem Mass Spectrometry. At the conclusion of the Blood Serum Study, Sonic Healthcare measured, on the same instruments in batches, biochemical markers of health in blood samples collected from the exposed and comparison communities.

For analysis, we considered PFAS that were detected in at least 80% of blood samples of participants from the exposed and comparison communities. Where blood serum PFAS concentrations were below the limit of quantification, we replaced values with the limit divided by the square root of two.

Due to the positively skewed distributions of blood serum PFAS concentrations, we analysed log-transformed values. We estimated the ratio of the geometric means of serum PFAS concentrations in participants from the exposed communities and comparison communities. We estimated the proportions of participants from the exposed communities with elevated (higher than background) serum PFAS concentrations. We defined individual elevated serum PFAS concentrations in age categories as the 95th percentile of serum PFAS concentrations in the comparison population. We used data from the Cross-sectional Survey to identify risk factors for an elevated serum PFAS concentration among residents of the exposed communities, including ingestion of bore water, consumption of certain locally grown produce, exposure to firefighting foams in the workplace and community, and length of residence in the exposed community. We estimated odds ratios of elevated serum PFAS concentrations for these risk factors, adjusted for demographic characteristics. We also examined associations between serum PFAS concentrations and serum biochemical markers of liver, kidney and thyroid function, and serum lipids. We estimated prevalence ratios and differences in mean biomarker concentrations per doubling in serum PFAS concentrations in participants from the exposed communities, adjusted for potential confounders.

Results

We recruited 2,392 adults and 195 children from the PFAS Management Areas in Katherine, Oakey and Williamtown and 702 adults from Alice Springs, Dalby and Kiama and Shellharbour for the Blood Serum Study. In total, 32% (817/2,587) of participants from the exposed communities were current residents of one of the PFAS Management Areas at the time of blood collection. Of the Blood Serum Study participants from the exposed communities, 34% (879/2,587) also participated in the Cross-sectional Survey in 2019 and 34% (867/2,587) consented to further biomarker testing of their blood sample. Overall, 99% (693/702) of participants from the comparison communities also participated in the Cross-sectional Survey in 2020 and 99% (692/702) consented to further biomarker testing of their blood sample.

We detected perfluorooctane sulfonic acid (PFOS), perfluorohexane sulfonic acid (PFHxS) and perfluorooctanoic acid (PFOA) in the blood serum samples of more than 80% of participants from exposed and comparison communities. Across the exposed communities, the geometric means of blood serum PFAS concentrations ranged from 4.9 to 6.6 nanograms per millilitre (ng/mL) for PFOS, from 2.9 to 3.7 ng/mL for PFHxS and from 1.3 to 1.8 ng/mL for PFOA. Geometric means of PFAS concentrations were higher in older participants and in males. In Oakey and Williamtown, serum PFOS and PFHxS concentrations were also higher in participants who lived in a section of the PFAS Management Area located closer to the military base (the Primary Zone) with higher concentrations of PFAS in the environment.

Across the comparison communities, the geometric means of serum PFAS concentrations ranged from 2.5 to 3.3 ng/mL for PFOS, from 0.7 to 1.2 ng/mL for PFHxS and from 1.2 to 1.4 ng/mL for PFOA. Geometric means of serum PFAS concentrations were higher in participants from exposed communities than participants from comparison communities. Geometric means of serum PFOS concentrations for the exposed communities ranged from 1.9 to 2.3 times as high as the comparison communities. Geometric means of serum PFHxS concentrations for the exposed communities ranged from 2.5 to 5.9 times as high as the comparison communities. In contrast, geometric means of serum PFOA concentrations ranged from 1.2 to 1.3 times as high as the comparison communities.

In total, 29% to 42% of participants from the exposed communities had an elevated serum PFOS concentration and 48% to 55% had an elevated serum PFHxS concentration. Only 6% to 14% of participants from the exposed communities had an elevated serum PFOA concentration. We identified several risk factors for a resident having an elevated serum PFOS or PFHxS concentration, including consuming bore water or certain locally grown foods at least weekly,

length of residence in an exposed community and occupational exposure to firefighting foams. There was considerable uncertainty in the associations of elevated PFOA concentrations with the risk factors we assessed. Residents of the PFAS Management Areas reported reducing their use of bore water and consumption of local produce after they were made aware of the PFAS contamination. For example, 78% of participants who lived in the exposed communities had stopped using bore water or used it for fewer activities in their household.

Elevated cholesterol concentrations (higher than the upper reference limit) were the most commonly observed 'abnormality' among participants from the exposed communities. In Williamtown, we observed higher prevalence of elevated total cholesterol per doubling in PFOS, PFHxS and PFOA serum concentrations and higher mean total cholesterol concentrations, low-density lipoprotein cholesterol concentrations and the total cholesterol to high-density lipoprotein cholesterol ratio. In Katherine and Williamtown, we observed higher prevalence of elevated urate (uric acid) per doubling in all PFAS serum concentrations. However, differences in mean serum lipid and urate concentrations per doubling in PFAS serum concentrations were small (close to zero). Estimates for adverse liver function biomarker concentrations per doubling in PFAS serum concentrations were mostly inconsistent across the exposed communities. In Williamtown, we observed higher prevalence of elevated alanine transaminase, gamma glutamyl transferase and alkaline phosphatase per doubling in PFAS serum concentrations; however, our findings were based on few cases with mild elevations of the concentrations of these liver function biomarkers and could be due to missing data.

These findings should be interpreted cautiously considering the study's limitations. Our study population is not representative of the general populations of Katherine, Oakey and Williamtown, or Alice Springs, Dalby, and Kiama and Shellharbour. Community members chose whether or not to participate in the Blood Serum Study and, therefore, our study population was 'self-selected', not randomly sampled. Participants may have been more or less likely to have been exposed to PFAS than non-participants. Further, blood serum PFAS concentrations and biochemical markers are samples collected at a single point in time and do not reflect historical exposure or health.

Conclusion

The Blood Serum Study shows evidence of higher serum PFOS and PFHxS concentrations in participants from the PFAS Management Areas in Katherine, Oakey and Williamtown, compared to participants from communities not affected by environmental PFAS contamination. However, serum PFOA concentrations in participants from the exposed communities are equivalent to the background exposure levels observed in the comparison communities. These findings are consistent with the nature of the contamination in the PFAS Management Areas and reflect the main ingredients of the firefighting foams historically used in the Areas. Serum PFAS concentrations across Katherine, Oakey and Williamtown are comparable to those reported for communities in the United States of America affected by environmental PFAS contamination from firefighting foam use on military bases, though lower than in a community in Sweden. The risk factors we identified for elevated PFOS and PFHxS concentrations in residents of PFAS Management Areas were consistent with what is known about exposure pathways in these Areas. Consuming bore water or certain locally grown foods were risk factors for elevated serum PFAS concentrations, however, changes in behaviour could limit people's intake of PFAS and blood levels generally decline naturally over time. This study of serum PFAS concentrations in people from the PFAS Management Areas provides important information for community members and policy makers.

Abbreviations

AFFF	Aqueous Film Forming Foam
ALT	Alanine transaminase
ALP	Alkaline phosphatase
AST	Aspartate transaminase
BMI	Body Mass Index
eGFR	Estimated Glomerular Filtration Rate
GGT	Gamma glutamyl transferase
g/L	Grams per litre
HDL	High-density lipoprotein
LDL	Low-density lipoprotein
mIU/L	Milli-international units per litre
mL/min/1.73 m^2	Millilitres per minute, relative to body surface area
mmol/L	Millimoles per litre
ng/mL	Nanograms per millilitre
NSW	New South Wales
NT	Northern Territory
OR	Odds ratio
PFAS	Per- and polyfluoroalkyl substances
PFBS	Perfluorobutane sulfonic acid
PFDA	Perfluorodecanoic acid
PFHpA	Perfluoroheptanoic acid
PFHxA	Perfluorohexanoic acid
PFHxS	Perfluorohexane sulfonic acid
PFNA	Perfluorononanoic acid
PFOA	Perfluorooctanoic acid
PFOS	Perfluorooctane sulfonic acid
pmol/L	Picomoles per litre
PR	Prevalence ratio
Qld	Queensland
RAAF	Royal Australian Air Force
RoM	Ratio of geometric means
TSH	Thyroid Stimulating Hormone
T3	Triiodothyronine
T4	Thyroxine
US	United States of America

U/L	Units per litre
VBTP	Voluntary Blood Testing Program
6:2 FTS	6:2 fluorotelomer sulfonic acid
µg/L	Micrograms per litre
µmol/L	Micromoles per litre

Introduction

Per- and polyfluoroalkyl substances (PFAS) are synthetic chemicals classified as contaminants of emerging concern due to their potential to adversely affect the environment and human health. Concerns over the widespread use and global distribution of PFAS have led to considerable scientific investigation and public interest regarding the effects of exposure to these chemicals on human health.[1] PFAS have been extensively used in industrial and consumer products since the 1950s and are universally detected in blood serum samples across the world due to their persistent and bioaccumulative properties.[1-4] However, communities in areas with contaminated water sources and land have been shown to have higher exposure to PFAS, which has the potential for both immediate impacts on psychological health and latent effects on physical health.[5] Understanding exposure to PFAS and the associated health effects is vital to informing public health responses and addressing community concerns in areas affected by environmental contamination.[6]

PFAS overview

PFAS are a group of more than 4,000 fluorinated, organic chemicals that contain at least one carbon atom that has all of its hydrogen substituents replaced by fluorine atoms.[7] Structurally, most PFAS consist of a carbon chain (alkyl chain) and a functional end group, such as an acid group.[7] PFAS vary in their properties depending on the structure and length of the carbon chain.[7] Perfluoroalkyl substances have a carbon chain that contains only fluorinated carbons.[7] Due to the strength of the carbon fluorine bonds, perfluoroalkyl substances remain stable under a variety of biological, chemical and thermal conditions.[7] In contrast, polyfluoroalkyl substances contain a carbon chain that has at least one fluorinated and one non-fluorinated carbon atom. Under specific conditions, some polyfluoroalkyl substances can break down into stable perfluoroalkyl substances.[7,8]

Many PFAS contain a functional end group that attracts water (hydrophilic), opposing the properties of the fluorinated carbon chain, which repels water (hydrophobic) and oil (oleophobic). As a result, PFAS have unique surface-active properties which make them effective in reducing surface tension and resistant to heat, oil, stains, grease and water.[7,9] Due to their stability and properties, PFAS are used for a wide range of purposes.[9] Initially, PFAS were manufactured for use in consumer products, such as fabric protectant and non-stick cookware. Later applications of PFAS include a range of industrial products, including aqueous film-forming foams (AFFF) which were used to extinguish liquid fuel fires in aviation settings. The extensive use of PFAS for household and industrial purposes since the 1950s, and the subsequent movement of PFAS through water sources and land, led to environmental contamination across the world.[10-12]

Perfluorooctane sulfonic acid (PFOS), perfluorohexane sulfonic acid (PFHxS) and perfluorooctanoic acid (PFOA) are the most widely studied PFAS and have been found to bioaccumulate in wildlife and humans.[7] The presence of these long-chain perfluoroalkyl substances (defined as ≥6–8 perfluoroalkyl carbons) in the environment is driven by environmental release from industrial and consumer products and the subsequent breakdown of larger polyfluoroalkyl substances.[7,13] The common use and widespread distribution of PFAS has led to increasing concerns about potential effects on the environment and human health.[1] In response, manufacturers have phased out of production many long-chain perfluoroalkyl substances over the past two decades.[1,7]

In Australia, studies of pooled blood serum samples of the general population have shown declines in PFOS, PFHxS and PFOA concentrations over time following the phase-out of their production and use.[2] However, exposure to PFAS through environmental contamination in specific populations

remains a public health concern. Worldwide, studies show significantly higher exposure to PFAS in populations living in areas affected by environmental contamination, compared to the general population.[1,14-17] In response, governments and international agencies have prioritised the remediation of environments contaminated with PFAS to reduce potential exposure. However, the stability of PFAS under varying environmental conditions and their sources are a current challenge to remediation efforts, requiring the development of innovative methods.[18-20]

Human health effects

Concerns over the potential for PFAS to adversely affect human health arise from the ease with which they are absorbed into and distributed through the body.[14,21] Human exposure to PFAS occurs predominantly through ingestion and absorption into the blood stream via the digestive tract, but may also occur through inhalation or absorption through the skin (dermal). Following exposure, several PFAS have been found to bind to serum albumin (a protein present in blood serum) resulting in accumulation in tissues with large blood supply, such as the kidneys and liver.[21,22] The elimination half-life[1] in human blood varies with the type of PFAS, ranging from 3–5 years for PFOS to 5–8 years for PFHxS and 2–3 years for PFOA.[23-25] However, ongoing exposure to PFAS through industrial and consumer products may affect the estimates of the half-lives[2] of these chemicals.

A rise in scientific and public interest in the potential health effects of PFAS exposure has led to substantial epidemiological and toxicological investigations, which indicate a range of potential effects on metabolism, immunity, reproduction and development. Systematic reviews of the epidemiological literature suggests that these effects include higher serum lipid levels (high cholesterol, known as hypercholesterolaemia), abnormal thyroid hormone levels and the suppression of some immune responses.[14,26-32] Reviews suggest associations of PFAS with adverse changes to liver function (through disruptions to bile acid uptake and lipid accumulation) and reductions in kidney function, as measured by estimated Glomerular Filtration Rate (eGFR).[27,33] There is additional evidence of an association between higher serum PFOA concentrations and hyperuricaemia, through a disruption to uric acid metabolism.[14] In addition to changes in metabolism, scoping reviews suggest an association between PFOA exposure and increased risk of testicular and kidney cancers.[33,34] Potential adverse effects on reproduction include decreased fertility through changes to testosterone levels in males and disruption to ovarian function in females.[35-37]

Key epidemiological studies

Epidemiological studies of communities affected by environmental contamination may provide insight into the potential health impacts of PFAS exposure. The results of individual studies, however, are not considered conclusive and must be weighed against studies of similar outcomes through systematic review. The C8 Health Project was conducted from 2005 to 2013 in approximately 69,000 residents of areas in Ohio and West Virginia who consumed drinking water contaminated with PFOA.[16] The C8 Health Project found evidence for increased risks of the following health outcomes associated with blood serum concentrations of PFOA: hypercholesterolaemia; pregnancy-induced hypertension; thyroid disease; testicular and kidney

[1] The elimination half-life of a substance in the body is a measurement of the length of time required for the body to eliminate half of the substance by normal physiological processes.

[2] In many studies, the elimination half-life is estimated by monitoring the rate of elimination from the body, without considering potential ongoing exposure (or other physiological changes). In such studies, the observed half-life is often referred to as an 'apparent half-life' (where the elimination rate is a result of ongoing exposure, adsorption and distribution in the body, as well as elimination). If there is an ongoing exposure, the apparent half-life is likely to be longer compared to the 'intrinsic' (true) elimination half-life (estimated from the elimination alone).

cancer; and ulcerative colitis.[38] Similarly, an epidemiological study of PFOA exposure in residents of the Veneto region of Northern Italy reported a range of adverse health effects: increased all-cause and cause-specific mortality rates, including COVID-19 mortality rates; changes in cholesterol levels of women during pregnancy, including an increase in total cholesterol in the first trimester; delayed or irregular menstruation in young women; and decreased biochemical markers of fertility in young men.[17,39-42]

Individual epidemiological studies across Sweden show evidence of increased serum PFOS and PFHxS concentrations in communities affected by environmental contamination from AFFF. The Prospective Investigation of the Vasculature in Uppsala Seniors Study, conducted from 2001 to 2014, investigated the health effects of PFAS exposure in elderly residents of Uppsala, Sweden. Residents were exposed to drinking water contaminated with AFFF from a nearby military airport.[43] A study of the affected residents found a positive association between serum concentrations of several PFAS, including PFOS, and carotid atherosclerosis.[43] Another cohort study of pregnant women and their offspring conducted from 1996 to 2017 in Uppsala reported potential adverse effects on fetal and childhood development. Higher serum PFOA, PFOS and PFHxS concentrations in mothers were associated with higher Body Mass Index (BMI) in their children at 3–5 years.[44] A study of approximately 63,000 people who lived in Ronneby, Sweden from 1980 to 2013 reported an association between higher serum PFAS concentrations and higher total cholesterol and low-density lipoprotein (LDL) concentrations.[15] Further studies reported an association between higher serum PFAS concentrations and changes to gene expression related to the development of cardiovascular disease, dementia and cancers.[45,46] Individual epidemiological studies of environmental contamination from historic AFFF use in the United States of America (US) also reported higher serum PFOS and PFHxS concentrations in residents and workers of the affected communities, compared to the general population. However, investigations of the health risks in these populations are ongoing, with the results not yet published.[47-49]

PFAS contamination in Australia

In Australia, PFAS contaminations have occurred in environments surrounding firefighting training grounds, airports and military bases where AFFF were in frequent use. From the 1970s, AFFF were used at Australian Defence Force bases for fire emergencies and training purposes.[50-53] Predominantly, Australian Defence Force bases utilised the product 3M Light Water™, which contains PFOS and PFHxS as the main active ingredients.[50,51,53,54] In 2002, the 3M Company ceased the production of Light Water™ due to environmental and human health concerns. The Department of Defence discontinued use of Light Water™ across Australian military bases over the following years, replacing the product with Ansulite™ — a fluorotelomer-based foam.[55,56]

PFAS Management Areas

From 2013 to 2017, the Australian Government identified PFAS contamination affecting the environment surrounding the Royal Australian Air Force (RAAF) Bases at Tindal in Katherine, Northern Territory (NT) and Williamtown in New South Wales (NSW), and the Army Aviation Centre in Oakey in Queensland (Qld).[57-59] Environmental investigations of PFAS in groundwater, surface water, sediment and soil showed the extent of contamination on the military bases and off-base areas, including surrounding residential properties.[60-62] The affected environments, referred to as PFAS Management Areas, contain varying concentrations of PFAS depending on the historic use of AFFF and other factors, including the direction of groundwater flow through aquifers and the spread of surface water through drains, waterways and flooding events.[60-62] However, PFAS concentrations were highest in water sources and land located in close proximity to the military bases, represented by Primary Zones within the PFAS Management Areas.[50-52]

The main PFAS exposure pathways in Katherine, Oakey and Williamtown are the consumption of local bore water (extracted from groundwater) — including incidental consumption via bathing and swimming — and the consumption of local produce watered with bore water or grown in contaminated soil, which may have also been affected by surface water.[50-52] Consumption of fish or crustaceans sourced from local rivers and waterways is an additional exposure pathway for the affected communities.[50-52] The Australian Government and state and territory governments provided advice to residents of these PFAS Management Areas to minimise potential sources of exposure to PFAS. These precautions were informed by risk assessments incorporating the environmental site investigations of groundwater, surface water and local produce, including livestock, poultry, seafood, and fresh fruit and vegetables.[50-52] Contamination of the local environments in Katherine, Oakey and Williamtown led to substantial community concern and public interest in the potential human health effects.

PFAS Health Study

In response to the contamination events, the Australian Department of Health commissioned the Australian National University (ANU) to conduct an epidemiological study to investigate exposure to PFAS and the related health effects in Katherine, Oakey and Williamtown. To coincide with the epidemiological study, the Department of Health introduced the Voluntary Blood Testing Program (VBTP) for PFAS for people who had ever lived or worked in these PFAS Management Areas. The PFAS Health Study was conducted in two phases.

In Phase I, the PFAS Health Study team conducted a systematic review to examine the health effects of PFAS in humans as reported in literature published until February 2017.[63] The review reported sufficient evidence for an association of higher blood serum concentrations of PFOA and PFOS with increased serum total cholesterol concentrations. The review identified limited evidence for a positive association of serum PFOA and PFOS with serum uric acid concentrations, an inverse association between serum PFOA and PFOS and eGFR, and a positive association of serum PFOA and PFOS with prevalence of chronic kidney disease. Together, these findings suggest a potential association between high serum PFAS concentrations and impairment of kidney function in humans. The review further reported limited evidence for a positive association between exposure to PFOA and kidney and testicular cancer, and an inverse association between exposure to a range of PFAS (including PFOS and PFOA) and antibody levels of diphtheria and rubella after vaccination.

Phase II included an epidemiological study of the three PFAS-affected communities noted above, comprising four studies which are detailed below.

Focus Groups Study

The PFAS Health Study team conducted the Focus Groups Study to understand the views, experiences and concerns regarding PFAS among individuals who lived or worked in the towns of Katherine, Oakey and Williamtown. Three focus groups of 29 people in Katherine, 36 in Oakey and 46 in Williamtown occurred between January and August 2018. Additional focus groups were held in three local Aboriginal communities in Katherine, with 69 participants in August 2018. The findings of the focus group discussions were published in a report released in February 2019 and subsequently, in a peer-reviewed journal article.[6,64]

Blood Serum Study

The Blood Serum Study (detailed in this report) compared blood serum PFAS concentrations in residents and workers from the three PFAS Management Areas (the ‘exposed communities’) and residents of three communities not affected by environmental PFAS contamination (the ‘comparison communities’): Alice Springs in the NT, Dalby in Qld, and Kiama and Shellharbour in

NSW. Participants from the exposed communities were a sub-sample of people who undertook blood testing through the VBTP between 2016 and 2019. Participants from the comparison communities were randomly selected to participate in the PFAS Health Study from the Medicare Enrolment File in 2020. A pathology laboratory tested blood serum samples of participants from the exposed and comparison communities for a range of PFAS, as well as several biochemical markers of health, including serum lipids and markers of kidney, liver and thyroid function.

Cross-sectional Survey

The Cross-sectional Survey investigated the health of residents and workers from the exposed communities and residents of the comparison communities. Participants completed a survey about whether or not they had ever experienced any of a range of health outcomes. The survey also assessed psychological well-being and distress and collected data on sociodemographic characteristics. Participants from the exposed communities completed the survey in 2019, following the end of the VBTP. Participants from the comparison communities were invited to participate in the Cross-sectional Survey at the same time as the Blood Serum Study in 2020.

Data Linkage Study

The Data Linkage Study examined whether rates of adverse health outcomes were higher among people who had lived in the PFAS Management Areas than among people who had lived in similar areas in Australia not affected by environmental contamination. Using linked administrative data collected over time, the study investigated maternal and infant (perinatal) health, childhood development, cancer and cause-specific mortality outcomes.

Blood Serum Study

Aims and objectives

The aim of the Blood Serum Study was to examine whether people who lived or worked in the PFAS Management Areas of Katherine, Oakey and Williamtown (the 'exposed communities') had higher blood serum PFAS concentrations than people who live in communities not affected by environmental PFAS contamination (the 'comparison communities'). Secondary aims of the study were to examine potential exposure pathways to PFAS in the exposed communities, identify risk factors for elevated levels of exposure in residents of the exposed communities, and assess the cross-sectional associations between blood serum PFAS concentrations and blood serum biochemical markers of health, including kidney, liver and thyroid function and lipid (e.g., cholesterol) concentrations.

Research questions

The main research questions were:

1. What are the mean serum concentrations of PFAS in Katherine, Oakey and Williamtown residents and workers and how do these levels compare to those of people residing in non-contaminated areas?
2. How do serum concentrations vary by location and demographic factors, such as age and sex and length of residence, in the townships of Katherine, Oakey and Williamtown?
3. Does the geographic distribution of blood PFAS levels correlate with known zones of contamination of groundwater and soil?
4. What are the main potential sources of exposure to PFAS through occupation, food, waters or other factors in Katherine, Oakey and Williamtown?
5. What are the main risk factors for elevated (higher than background level) serum PFAS concentrations regarding demographic and other factors?

6. How do serum concentrations of PFAS in Katherine, Oakey and Williamtown residents correlate with blood markers of disease risk, such as cholesterol and kidney function?

Report structure and content

In this report, we detail the methods, results and conclusions of the second component of the PFAS Health Study — the Blood Serum Study. The Study draws on data collected in the Cross-sectional Survey, including information on participants' history of residence or work in the PFAS Management Areas, sources of exposure to PFAS and demographic characteristics. The Blood Serum Study and the Cross-sectional Survey were undertaken contemporaneously, with participants in the exposed and comparison communities invited to complete the survey at the time of, or after, blood sample collection for the Blood Serum Study. In this report, blood serum PFAS concentrations are analysed as an outcome, with the exception of analysis of biochemical markers of health, where blood serum PFAS concentrations are analysed as an exposure. The results of the Blood Serum Study are presented in four sections: serum PFAS concentrations in Katherine, Oakey and Williamtown; serum PFAS concentrations in exposed versus comparison communities; risk factors for elevated serum PFAS concentrations; and biochemical markers of health. Throughout this report, we cross-reference the methods, results and conclusions of the PFAS Health Study Component three: Cross-sectional survey of self-reported physical and mental health outcomes and associations with blood serum PFAS, hereafter referred to as the Cross-sectional Survey report.[65] The Cross-sectional Survey report presents findings on self-reported health, psychological distress, and participants' health concerns and experiences regarding the environmental PFAS contamination.[65]

Methods

Study design and recruitment

We conducted the Blood Serum Study to investigate exposure to PFAS in Australian communities affected by environmental contamination compared to similar communities without contamination.

Exposed population

The exposed population for the study included people who had lived or worked in the PFAS Management Areas in Katherine, Oakey and Williamtown, which were defined by the Australian Government Department of Defence based on environmental sampling of land and water sources.[60-62]

The VBTP conducted from 2016 to 2019 formed the basis of the Blood Serum Study. Under the Program, children and adults who had ever lived or worked in the PFAS Management Areas in Katherine, Oakey and Williamtown were eligible to access a free blood test to measure PFAS concentrations, with appropriate pre- and post-test consultations with their general practitioner (GP). People who were not currently living in PFAS Management Areas could access the program by consulting with their GP and completing a Statutory Declaration. All individuals who participated in the VBTP were invited on the pathology request form to participate in the Blood Serum Study.

We recruited participants from exposed communities for the Blood Serum Study from 23 November 2016 to 30 June 2019 in Williamtown and Oakey and from 8 March 2018 to 30 June 2019 in Katherine. At the time of blood sample collection, participants gave informed consent to participate in the Blood Serum Study. For children under the age of 16 years old, a parent or guardian provided consent for their child to participate in the Study. In August 2019, we invited Blood Serum Study participants to complete a survey about their potential exposure to PFAS, their physical and mental health status and demographic characteristics — the Cross-sectional Survey. We invited participants to have their stored blood sample tested for biomarkers of kidney, liver and thyroid function and serum lipids. In December 2020, we invited participants who had consented to take part in the Blood Serum Study but who had not participated in the Cross-sectional Survey to consent to have their blood sample tested for these biomarkers and to complete a shorter version of the survey. The study design and methods of the Cross-sectional Survey are detailed in the Cross-sectional Survey report.[65]

Comparison population

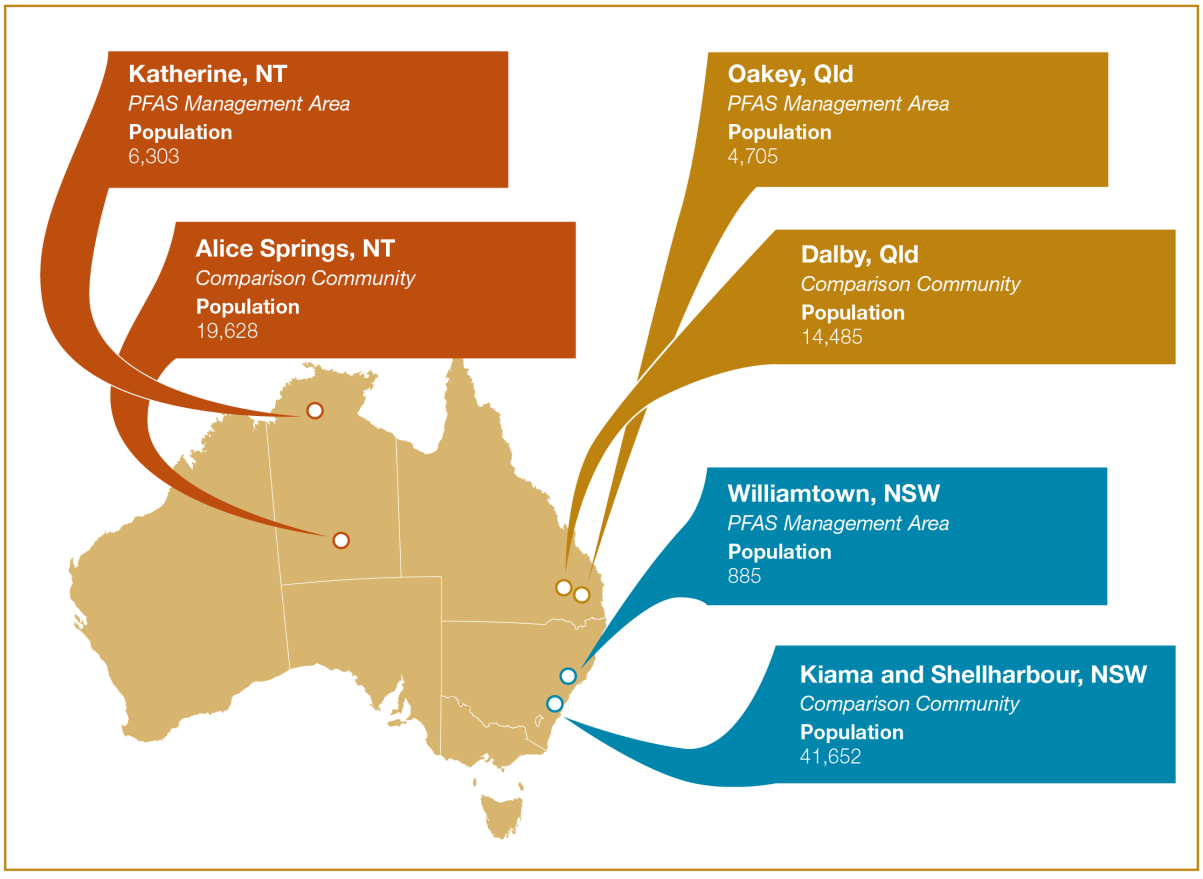
To assess whether serum PFAS concentrations were higher in residents and workers from the exposed communities, we chose three comparison communities that were similar to the PFAS Management Areas and within the same state or territory. The comparison communities for the Study were not known to be affected by environmental PFAS contamination, according to the water quality guideline values for PFAS developed by the Australian Government Department of Health, Food Standards Australia New Zealand and the National Health and Medical Research Council.[66] The three comparison communities were Alice Springs in the NT, Dalby in Qld, and Kiama and Shellharbour in NSW. We selected the comparison communities based on area-level (postal areas) attributes including sociodemographic characteristics (Socio-Economic Indexes for Areas) and remoteness (Accessibility and Remoteness Index of Australia), according to the Australian Bureau of Statistics 2016 Census data. We considered the proportion of Aboriginal and Torres Strait Islander persons in the community. Based on an expected participation rate of 2%, we required a minimum population of 10,000 residents in each comparison community. The final

selection of the comparison communities was based on access to pathology services for blood collection, to align with the data collection methods used for the exposed communities.

On behalf of the ANU study team, Services Australia (the Australian Government agency responsible for Medicare) randomly sampled individuals from the comparison communities using the Australian Government Medicare Enrolment File, based on residents of the postcodes 0870 (Alice Springs), 4405 (Dalby), and 2529 and 2533 (Kiama and Shellharbour). We recruited participants from comparison communities from 10 August to 5 October 2020. Services Australia sent 10,000 randomly selected adult residents (≥16 years old) from each comparison community an invitation to participate in the PFAS Health Study. Residents were contacted using a tiered approach over eight weeks, which included a reminder letter sent by Services Australia two weeks after the initial invitation. We provided information on the purpose of the study and instructed residents to register for the study online or via telephone. At the time of recruitment for the study, we also invited participants to take part in the Cross-sectional Survey. We sent potential participants two reminders to participate in the PFAS Health Study components.

A map of the exposed and comparison communities is shown in Figure 1.

Figure 1. Map showing PFAS Management Areas in Katherine, Oakey and Williamtown, and corresponding comparison communities and their associated populations for the PFAS Health Study Blood Serum Study.



Population data sourced from 2016 Census QuickStats.[67]

Data collection and measurement

Phlebotomists at Sonic Healthcare pathology collection centres across Australia collected participant blood samples in a single BD vacutainer Serum Separator Tube. Participants were not asked to fast prior to blood sample collection. Serum samples were stored at 2–8°C and transported to the Sonic Healthcare laboratory in Brisbane, Australia, for analysis. Sonic Healthcare analysed the samples for nine PFAS: PFOA, PFOS, PFHxS, perfluorobutane sulfonic

acid (PFBS), perfluorohexanoic acid (PFHxA), perfluoroheptanoic acid (PFHpA), perfluorononanoic acid (PFNA), perfluorodecanoic acid (PFDA) and 6:2 fluorotelomer sulfonic acid (6:2 FTS). Due to the potential for the carbon chain of some PFAS to appear in linear or branched forms in human blood, we quantified the total (sum of linear and branched) concentration of each PFAS in the serum samples. To assess potential differences in the health effects of linear and branched chain PFOS — related to variation in physical and chemical properties of the isomers — we also quantified linear and branched (1-methyl, other-methyl and di-methyl) concentrations separately. Details of the measurement of blood serum PFAS concentrations are shown in Box 1.

Box 1. Measurement of blood serum PFAS concentrations.

Sonic Healthcare vortexed and sonicated serum samples with a solvent for protein precipitation and PFAS extraction. They then centrifuged and filtered the mixture before analysis of PFAS concentrations using Liquid Chromatography Tandem Mass Spectrometry (LC-MS/MS). PFAS concentrations were measured in the range of approximately 0.2–100 nanograms per millilitre (ng/mL). Sonic Healthcare conducted routine quality control and calibration for all tests, and each sample was extracted and analysed in duplicate. Additionally, procedural blanks and a standardised reference material (NIST SRM 1957) were analysed together with each batch of samples to control for contamination and accuracy.

Following PFAS measurement in the VBTP, Sonic Healthcare transported aliquots of blood serum samples to the ANU at quarterly intervals and provided reports of test results. Serum aliquots were labelled with date of collection, time of collection, personal identification number, initials of the participant and the pathology barcode. At the ANU, serum aliquots were stored in cryogenic boxes at −80°C in a secure freezer. For participants from the comparison communities, blood serum samples were measured for PFAS and then temporarily stored at Sonic Healthcare for biochemical marker testing. At the conclusion of the data collection in comparison communities, serum aliquots stored at the ANU were transported to Sonic Healthcare for biochemical marker testing, in accordance with participant consent preferences. Serum samples were analysed by Sonic Healthcare for 15 biochemical markers of health, including kidney, liver and thyroid function tests and serum lipids and proteins. We then calculated eGFR and the total cholesterol to HDL cholesterol ratio (total cholesterol/HDL cholesterol), as described in the Data Analysis section below. A description of the biomarkers is provided in Table 1. We selected these biomarkers of health for investigation in the Blood Serum Study based on the conclusions of the PFAS Health Study Systematic Review, conducted from 2016 to 2018, and recent scientific publications.[63,68] Biomarkers were measured according to standard Australian pathology testing protocols and the tests were conducted in batches over the same time period, using the same test instrument for samples from exposed and comparison communities. Following biochemical marker testing, Sonic Healthcare transferred the serum samples to a secure bio-banking facility located at the University of Queensland, in accordance with participant consent preferences for future research.

Table 1. Biochemical markers measured in the Blood Serum Study and associated clinical endpoints.

Biochemical markers	Clinical endpoints
Lipid Profile: total cholesterol, HDL cholesterol, LDL cholesterol, triglycerides, total cholesterol to HDL ratio	Biochemical marker of cardiovascular disease risk
Kidney function tests: serum creatinine, eGFR, urate (uric acid)	Biochemical marker of kidney disease
Liver Function tests: ALT, AST, GGT, ALP, serum albumin, total protein	Biochemical marker of liver disease
Thyroid function tests: TSH, free T3, free T4	Biochemical marker of thyroid disease

HDL: high-density lipoprotein; LDL: low-density lipoprotein; eGFR: estimated Glomerular Filtration Rate; ALT: alanine transaminase; AST: aspartate transaminase; GGT: gamma glutamyl transferase; ALP: alkaline phosphatase; TSH: thyroid stimulating hormone; T3: triiodothyronine; T4: thyroxine.

Reporting

Blood serum PFAS concentrations were reported to participants in exposed communities through the VBTP. At the end of the Blood Serum Study, we reported the serum PFAS concentrations to participants in comparison communities. We also reported results for all biomarker tests for participants from the exposed and comparison communities at the end of the Blood Serum Study. Details about reporting are described in the Cross-sectional Survey and Blood Serum Study protocol.[69] Biomarker reference ranges, based on age and sex, were provided to participants and results outside the normal reference ranges were noted. Where participants had provided consent, a report was also sent to their GP. Doctors for participants in comparison communities were provided with information about PFAS and potential health effects, including the limitations of PFAS blood testing in individuals.

Data analysis

The Blood Serum Study included analyses of serum PFAS concentrations and biochemical markers of health. Importantly, serum PFAS concentrations are analysed as both an outcome and exposure variable in the Study, as detailed in the sections below. Further, several exposure variables and covariates included in our analyses use data from the Cross-sectional Survey and therefore, we restricted certain analyses to participants who completed both components of the PFAS Health Study.

Outcomes

Serum PFAS concentrations

Sonic Healthcare measured blood serum concentrations of nine PFAS: PFOS, PFHxS, PFOA, PFBS, PFHxA, PFHpA, PFNA, PFDA and 6:2 FTS. We analysed data on blood serum PFAS concentrations where the detection frequency was more than 80% in the study population. In the main analysis, we replaced values below the limit of quantification with the limit divided by the square root of two, following standard scientific convention.[70] To address the potential bias induced by this single imputation, in a sensitivity analysis we treated values below the limit of quantification as censored values, which we imputed using multiple imputation by chained equations.[70]

We considered serum PFAS concentrations as both continuous and binary variables. We categorised elevated (higher than background) exposure based on the 95th percentile of serum

PFAS concentrations in participants from the comparison communities, by age categories (16–49, 50–69 and ≥70 years old) and for each PFAS included in our analysis. For each PFAS, we used a single cut-off for elevated serum PFAS concentrations across the comparison communities as the 95th percentile did not significantly differ among participants from Alice Springs, Dalby and Kiama and Shellharbour.

Biochemical markers of health

Sonic Healthcare measured biochemical markers of liver, kidney and thyroid function and lipid concentrations in blood serum samples. We analysed these biomarkers as both continuous and binary outcomes. Depending on the biomarker, binary outcomes were defined as adverse outcomes: 'high/elevated' (above the upper reference interval limit) or otherwise, 'low' (below the lower reference interval limit) or otherwise, and 'abnormal' (outside the reference interval) or otherwise. The biochemical marker reference ranges are shown in Table A1-1.

Lipid biomarkers included total cholesterol (millimoles per litre (mmol/L)), HDL cholesterol (mmol/L), low-density lipoprotein (LDL) cholesterol (mmol/L) and triglycerides (mmol/L). We calculated the total cholesterol to HDL cholesterol ratio. We defined high total cholesterol as above 5.5 mmol/L, low HDL cholesterol as below 0.9 mmol/L for males and 1.1 mmol/L for females, high LDL cholesterol as above 4 mmol/L, high total to HDL cholesterol ratio as above 4.5 and high triglycerides as above 2 mmol/L.

Liver biomarkers included alanine aminotransferase (ALT) (units per litre (U/L)), aspartate transaminase (AST) (U/L), gamma glutamyl transferase (GGT) (U/L), alkaline phosphatase (ALP) (U/L), serum albumin (grams per litre (g/L)) and total protein (g/L). We defined high ALT as above 40 U/L for males and 30 U/L for females, high AST as above 40 U/L for males and 35 U/L for females and high GGT as above 40 U/L for males under 18 years of age, above 50 U/L for males 18 years and over and above 30 U/L for females. We excluded binary total protein from our analyses as the other liver function biomarkers that we measured are more sensitive markers of liver function. High ALP and low serum albumin were defined by age and sex categories as described in Table A1-1. We did not include low serum albumin in our analyses due to the low prevalence.

Kidney function biomarkers included serum creatinine (micromoles per litre (µmol/L)) and urate or uric acid (millimoles per litre (mmol/L)). We calculated the eGFR (millilitres per minute, relative to body surface area (mL/min/1.73 m^2)) based on age, sex and serum creatinine using the Chronic Kidney Disease Epidemiology Collaboration (CKD-EPI) formula.[71] We defined low eGFR as below 60 mL/min/1.73 m^2 and high urate (uric acid) as above 0.5 mmol/L for males, above 0.38 mmol/L for females under 16 years of age and above 0.40 mmol/L for females 16 years and over. High serum creatinine was defined by age and sex categories as described in Table A1-1.

Thyroid biomarkers included thyroid-stimulating hormone (TSH) (milli-international units per litre (mIU/L)) and the concentration of two thyroid hormones in free circulation: free triiodothyronine (T3) (picomoles per litre (pmol/L)) and free thyroxine (T4) (pmol/L). We defined abnormal TSH concentrations as below 0.3 mIU/L or above 4.2 mIU/L for participants under 18 years of age, above 3.5 mIU/L for participants 18 to <50 years of age, above 4 mIU/L for participants 50 to <70 years of age and above 5 mIU/L for participants 70 years and over. Hypothyroidism (subclinical or primary) was defined as high TSH and low or normal free T4 (defined as 19.0 pmol/L and below for participants aged less than 70 years and 20.0 pmol/L and below for participants 70 years and over). Hyperthyroidism (subclinical or primary) was defined as low TSH and normal or high free T3 (defined as 3.0 pmol/L and above for participants aged less than 18 years, 2.6 pmol/L and above for participants aged 18 to <70 years and 2.3 pmol/L and above for participants 70 years and over) or free T4 (defined as 9.0 pmol/L and above for participants aged less than 70 years and 10.0 pmol/L and above for participants 70 years and over). We did not include hypothyroidism and hyperthyroidism in our analyses due to low prevalence among the study population.

Exposures

Analysis of serum PFAS concentrations

We considered the following exposure variables in our analyses of serum PFAS concentrations.

1. Community membership, defined as residence or work in the PFAS Management Areas of Katherine, Oakey and Williamtown versus the corresponding comparison communities of Alice Springs, Dalby, and Kiama and Shellharbour.
2. Residence location, defined as residence in the Primary, Secondary or Broader Zones of the PFAS Management Areas of Oakey and Williamtown.
3. Residence length, defined as the total number of years of residence in the PFAS Management Areas of Katherine, Oakey and Williamtown.
4. Demographic factors.
5. Potential sources of PFAS exposure in the PFAS Management Areas, including ingestion of bore water, consumption of locally grown produce and exposure to AFFF.

We assessed community membership, residence location and residence length based on self-reported address and residence and/or work history at the time of blood sample collection and survey collection. We used two definitions of community membership, denoted as 'residence/work status': (1) ever living or working in the PFAS Management Areas, referred to as 'ever exposed participants'; (2) and current residence in the PFAS Management Areas, referred to as 'current residents'. We defined current residents as participants who had an address within the PFAS Management Areas of Katherine, Oakey or Williamtown at the time of blood collection. To determine the addresses within the PFAS Management Areas and the residence location (within the Primary, Secondary and Broader Zones of the PFAS Management Areas) we constructed an address database. Details of the PFAS Management Area address database are shown in Box 2. We re-classified participants recruited from the comparison communities who reported ever living or working in the PFAS Management Areas as 'ever exposed participants' based on residential and work history reported in the Cross-sectional Survey.

Box 2. PFAS Management Area address database.

The boundaries of the PFAS Management Areas and the Primary, Secondary or Broader Zones, defined by the Department of Defence, are available as a set of vector coordinates — longitude and latitude values — that demarcate the catchment areas. We used these coordinates to extract all relevant street addresses that fell inside the catchment areas, and those that lay on the boundaries, from the Geocoded National Address File (G-NAF). The G-NAF contains address data for over 14 million physical addresses in Australia including state, suburb, street, number and coordinates. The G-NAF does not contain any personal information or details relating to an individual or business.

The address database comprised a total of 5,883 street addresses: 3,007 addresses in Katherine, 1,958 in Oakey, and 918 in Williamtown. We used ArcGIS v 10.7.1 software to facilitate the extraction of street addresses.

The G-NAF was sourced from the Department of Industry, Science, Energy and Resources.[72]

We defined the age and sex of participants based on information reported at the time of blood collection, however, we cross-referenced all the demographic information with data from the Cross-sectional Survey, when available.

We assessed the risk of PFAS exposure through food and water sources for residents of the PFAS Management Areas, using the PFAS exposure pathways and sources identified in the Australian Government Department of Defence Human Health Risk Assessments.[50-52] Specifically, we examined ingestion of bore water and consumption of local produce in accordance with the classification of exposure pathways for adult residents reported in the Risk Assessments. We used data from the Cross-sectional Survey on participants' consumption prior to learning about PFAS

contamination in their community. Participants were asked how frequently they used bore water at their residence on a six-point scale ('daily', 'about weekly', 'about monthly', 'less than once a month', 'not at all' and 'don't know') for eight activities, including: drinking; cooking; showering or bathing; watering or irrigating crops; watering vegetable gardens; swimming or wading pools; lawn watering; and giving water to livestock. Participants who had lived in more than one property with a bore water supply were asked to report their bore water use at the most recent residence. Using the same six-point scale to define frequency, participants were asked how often they ate foods produced on their property or by neighbours or local farmers in a PFAS Management Area for seven types of food: fruit and vegetables; eggs; poultry; livestock; seafood, shellfish or crustaceans, or freshwater fish; game meat and eggs; and locally foraged bush tucker.

We defined frequent ingestion of bore water as at least weekly ingestion of a residential bore water supply, including through drinking or cooking, or incidentally through bore water through bathing/showering or swimming. We defined infrequent ingestion of bore water as ingestion of a residential bore water supply less than weekly, including never. We classified the frequency and type of bore water ingestion based on whether a participant reported ever using bore water for drinking, cooking, bathing/showering or swimming, at least weekly prior to learning about the contamination. We assessed alternative pathways of exposure through bore water use in a sensitivity analysis, which we describe in the statistical analysis section.

For each PFAS Management Area, we defined frequent consumption of high-risk local produce as at least weekly consumption of locally sourced produce associated with elevated PFAS intake.[50-52] We defined high-risk local produce as eggs, fish, shellfish and crustaceans in Katherine; eggs, fish, fruit and vegetables, and livestock in Oakey; and eggs, fruit and vegetables, and livestock in Williamtown. We defined infrequent consumption of high-risk local produce as less than weekly, including never. In the same way as for bore water ingestion, we classified the frequency and type of local produce consumption based on a participant ever consuming high-risk local produce, at least weekly, prior to learning about the contamination.

In addition, we assessed exposure to AFFF based on potential exposure pathways reported by participants in the PFAS Health Study Focus Groups Study conducted in 2018 and other epidemiological studies.[64,73] We classified exposure to AFFF as exposure in the workplace (occupational) and exposure in the household or community, according to self-reported exposure history in the Cross-sectional Survey. Participants were asked if they had been exposed to AFFF in their current or a previous job, and separately, if they had been directly exposed to AFFF in their community. Participants who reported exposure to AFFF were asked to provide a description on how they were exposed, including the job title and industry in the case of workplace AFFF exposure. We defined occupational exposure to AFFF as current or previous firefighters and people who had ever been exposed to firefighting foams through firefighting-related activities in their workplace, such as emergencies or training. We defined community exposure to AFFF as people ever exposed to AFFF through non-occupational uses, including use of the foams for entertainment purposes or household maintenance and cleaning.

Analysis of biochemical markers of health

We considered blood serum PFAS concentrations as the exposure variable in our analyses of biochemical markers of health. We log-transformed (base 2) serum PFAS concentrations to express effects per doubling in PFAS serum concentrations. We used this scale so that effect sizes are comparable across the communities and for ease of interpretation.

Covariates

In our analysis of serum PFAS concentrations, we included age, sex, and residence or work in more than one PFAS Management Area as potential confounders.

In our analysis of biochemical markers of health, we considered the following sociodemographic and health-related factors as potential confounders: age, sex, highest level of education (combined into three categories: bachelor degree level and higher, certificate or diploma, and high school and lower and gross household annual income (five categories: ≤$25,999, $26,000–$64,999, $65,000–$129,999, $130,000–$233,999, ≥$234,000), smoking status (combined into two categories: never and ever) and alcohol consumption (categorised according to NHMRC guidelines: none, within guideline (≤10 standard drinks per week), exceeds guideline (>10 standard drinks per week)).[74] Categories were determined based on sample size and clinical relevance.

Statistical analysis

An overview of the main statistical analyses conducted as part of the Blood Serum Study is included in Table 2.

Table 2. Summary of statistical analyses for the Blood Serum Study.

Exposure variables	Purpose
Models of serum PFAS concentration	
Community membership: PFAS Management Areas and corresponding comparison communities	To compare serum PFAS concentrations in people who have lived or worked in the exposed communities, to people who live in communities not affected by environmental PFAS contamination.
Demographic factors	To assess whether serum PFAS concentrations vary by age and sex in people who have lived or worked in the exposed communities.
Primary, Secondary or Broader Zones of the PFAS Management Areas	To describe serum PFAS concentrations in people who live in the exposed communities in relation to known zones of contamination of groundwater and soil in the PFAS Management Areas.
Models of elevated serum PFAS concentration	
Potential sources of PFAS exposure and length of residence in the PFAS Management Areas	To identify risk factors associated with elevated serum PFAS concentrations in people who have lived in the exposed communities.
Models of biochemical markers of health	
Blood serum PFAS concentrations	To assess whether serum PFAS concentrations are associated with blood markers of disease risk, such as lipids (e.g., cholesterol) and kidney, liver and thyroid function.

Serum PFAS concentrations

Due to the right-skewed (positively skewed) distribution of blood serum PFAS concentrations, we analysed the (natural) log of PFAS and then reported the geometric means of PFAS concentrations for each of the exposed and comparison communities. An explanation of geometric mean is included in the Glossary. We summarised the median, 25th percentile, 75th percentile and the maximum and minimum values of blood serum PFAS concentrations in participants from each of the exposed and comparison communities. We used Spearman's rank correlation coefficient to describe the relationship between the serum concentrations of different types of PFAS.

We used log-linear regression models of serum PFAS concentrations to estimate the ratio of geometric means for females compared to males, and participants of different ages (0–15, 30–49, 50–69 and ≥70 years old compared to 16–29 years old). We estimated the ratio of geometric means of serum PFAS concentrations for current residents of the exposed communities who lived in the Primary and Secondary Management Zones, compared to residents of the Broader Management Zones. To assess whether residents and workers of Katherine, Oakey and Williamtown have higher levels of exposure to PFAS, we estimated the ratio of geometric means of serum PFAS concentrations in participants from the exposed communities, compared to residents of the comparison communities. We estimated the ratio of geometric means of serum PFAS concentrations for participants who had ever lived or worked in each of the PFAS Management Areas, compared to residents of the comparison communities, and for current residents of the PFAS Management Areas, compared to residents of the comparison communities. We estimated effects adjusted for age and sex. As children (0–15 years old) were not sampled in the comparison communities, we restricted this analysis to adult participants from the exposed communities.

Models were estimated via generalised estimating equations using an exchangeable correlation structure, to account for the correlation (clustering) of outcomes for participants within households. When convergence could not be achieved using an exchangeable correlation structure, we used an independence correlation structure and cluster-robust standard errors. We modelled age using a restricted cubic spline with three knots following assessment of the linearity of relationships between serum PFAS concentrations and age using univariable generalised additive models. In a sensitivity analysis, we treated blood serum PFAS concentrations below the limit of quantification as censored values that we imputed using multiple imputation by chained equations.

Elevated serum PFAS concentrations

We assessed the association of elevated serum PFAS concentrations and potential risk factors of PFAS exposure, including bore water ingestion, local produce consumption and exposure to AFFF. We summarised the proportion of participants with elevated serum PFAS concentrations by age and sex. We conducted our analyses of the risk factors for elevated serum PFAS concentrations using data collected in the Blood Serum Study and the Cross-sectional Survey, and therefore, excluded people who did not complete both components of the PFAS Health Study. We excluded participants who had only worked in the PFAS Management Areas due to limited information on bore water ingestion and local produce consumption in the workplace, as well as children due to low participation rates and different potential exposure pathways for infants and young children.

We summarised the proportion of participants with elevated serum PFAS concentrations for each of the assessed risk factors of PFAS exposure. For bore water use and local produce consumption, we included a summary of participant behaviours before and after they were made aware of the contamination.

We used multivariable logistic regression models with robust error variance to estimate odds ratios of elevated serum PFAS concentrations for adult participants who had ever lived in the PFAS Management Areas. We estimated effects adjusting for age, sex and living or working in multiple PFAS Management Areas. Models were estimated via generalised estimating equations, and we modelled age using a restricted cubic spline, as described from the analysis of continuous serum PFAS concentrations. In a supplementary analysis, we used multivariable log-linear regression to estimate the ratio of geometric means of serum PFAS concentrations for the assessed risk factors of PFAS exposure.

We conducted a series of sensitivity analyses for elevated serum PFAS concentrations.

1. Using an alternative definition of elevated serum PFAS concentrations (above the 95th percentile for the comparison population, by age categories (16–49, 50–69 and ≥70 years old) and sex (not included in the primary definition), for each PFAS included in the analysis.
2. Excluding exposed participants who had not resided in an exposed community in the 5, 10 and 15 years prior to survey completion because their PFAS serum concentrations at the time of blood collection may be least reflective of their long-term PFAS exposure levels.
3. Adjusting for potential pathways to eliminate serum PFAS (blood donation, blood transfusion, kidney dialysis and breastfeeding, each combined into binary categories: never and ever).
4. Including alternative pathways of bore water exposure (ingestion and dermal exposure to bore water, combined into a single binary category: never and ever frequent bore water exposure, defined as at least weekly).

Biochemical markers of health

We estimated the differences in mean biomarker concentrations per doubling in PFAS serum concentrations and prevalence ratios of 'adverse' biomarker concentrations per doubling in PFAS serum concentrations. We conducted our analyses of serum PFAS and biomarker concentrations using data collected in the Blood Serum Study and the Cross-sectional Survey, and therefore, excluded people who did not complete both components of the PFAS Health Study. Participants that consented to biomarker testing were a sub-sample of participants of the Blood Serum Study and the Cross-sectional Survey. We excluded children from these analyses due to low participation rates, as well as women who may have been pregnant at the time of blood sample collection (N = 21) due to changes in the biochemical marker concentrations during pregnancy.

We used multivariable linear regression models to estimate differences in biomarker concentrations and modified Poisson regression models with log link and robust error variance to estimate prevalence ratios of adverse biomarker concentrations. Models were estimated via generalised estimating equations and we modelled age using a restricted cubic spline, as described from the analysis of continuous serum PFAS concentrations. Linearity of relationships between outcome variables and continuous covariates were also assessed using univariable generalised additive models.

Models included an interaction term between PFAS and community membership so that PFAS effects were estimated separately for exposed and comparison communities. We report the effects estimated for each exposed community. Summary statistics and effect estimates for comparison communities are presented in Appendix 6 (Table A6-25 to Table A6-28) with the additional analyses of biochemical markers of health and not discussed further.

We estimated prevalence ratios of adverse biomarker concentrations and differences in mean biochemical marker concentrations adjusted by variables thought to affect both the exposure and outcome. In the primary analysis, we adjusted for sex, age and both education level and gross household annual income as measures of socioeconomic status. We modelled gross household annual income as an ordinal variable using category midpoints in the middle categories, and upper and lower limits in the lowest and highest categories, respectively. In a sensitivity analysis of the lipid biomarkers, liver biomarkers and serum urate, we assumed that renal excretion of PFAS (and thus PFAS serum concentrations) may be affected by kidney function and additionally adjusted for the eGFR and variables that may affect kidney function, including smoking status and alcohol consumption.[75]

We conducted a series of sensitivity analyses for biochemical markers of health.

1. Excluding exposed participants who currently reside in comparison communities.
2. Excluding exposed participants who had not resided in an exposed community in the 5, 10 and 15 years prior to survey completion and past workers, because their PFAS serum concentrations at the time of blood collection may be least reflective of their long-term PFAS exposure levels.
3. Assessing the impact of missing values in confounder variables using multiple imputation by chained equations.
4. Treating blood serum PFAS concentrations below the limit of quantification as censored values that we imputed using multiple imputation by chained equations.
5. Exclusion of participants with cancer-, cardiovascular-, autoimmune-, liver-, kidney- and thyroid-related comorbidities self-reported in the Cross-sectional Survey as diagnosed in the five years prior to blood collection in the case that treatment for these conditions affected biomarker values.

All data analyses and graphs for this report were generated using STATA software[3].

Interpretation of results

A guide to the interpretation of the results is shown in Box 3. The definitions of statistical terms used in this report are included in the Glossary.

Ethical considerations

The design and methods of the Blood Serum Study were approved by the Northern Territory Department of Health and Menzies School of Health Research Human Research Ethics Committee (protocol 2018-3130) and the ANU Human Research Ethics Committee (protocol 2016/707) in an initial ethics submission in 2016 and a series of amendments to each Committee from 2017 to 2020.

Data management

Data[4] use for the PFAS Health Study was governed by protocols approved by the Human Research Ethics Committees. The management of data complied with the ANU Privacy Policy and Australian Privacy Principles. The Study protocols outlined the management of all data collected and generated as part of the PFAS Health Study by the ANU Study team, stakeholders, contractors and third-party collaborators.

We stored all data securely on password protected ANU data servers during the collection and analysis stages of the Study. Personal identifying information was stored separately to research data used for analysis. Data were reported in aggregate form and were not personally identifiable. Personal identifying information was accessed by approved members of the study team for data linkage and administrative purposes. A unique participant identifying number was randomly assigned to each study participant. This was used to replace identifying information such as names, date of birth or address in research data used for analysis. The participant identification number was also used to link other identification numbers, such as blood serum sample and survey collection identifiers, and was not given to external collaborators.

[3] StataCorp. 2019. *Stata Statistical Software*: Release 16. College Station, TX: StataCorp LLC.

[4] Data collected includes all information collected or derived as part of the PFAS Health Study. This includes personal information, health surveys, linked data, research data, biometric data, reports, presentations, samples and correspondence. Data may be paper-based, digital or biological.

Box 3. Guide to the interpretation of results.

A relative effect measure — such as a ratio of geometric means (RoM), odds ratio (OR) or prevalence ratio (PR) — shows the relationship between an exposure and an outcome.

A ratio of geometric means is the ratio of the geometric mean of a continuous outcome in a group of people who are exposed to the geometric mean of the outcome in another group of people who are not exposed. For example, in the Blood Serum Study we estimated the ratio of geometric means of serum PFAS concentrations in residents and workers of the PFAS Management Areas and in residents of the comparison communities.

An odds ratio is the ratio of the odds of a binary outcome in a group of people who are exposed to the odds of the outcome in another group of people who are not exposed. In the Blood Serum Study, we estimated the odds ratio of elevated blood serum PFAS concentrations in people who ingest bore water compared to people who did not ingest bore water.

A prevalence ratio is the ratio of the prevalence (or proportion) of a binary outcome in a group of people who are exposed (or have higher serum concentrations of PFAS) to the prevalence in another group of people who are not exposed (or have lower serum concentrations of PFAS). In the Blood Serum Study, we estimated the prevalence of 'adverse' biomarker concentrations (e.g., elevated cholesterol levels) per doubling in serum PFAS concentrations.

Relative effect estimates include a point estimate and an accompanying 95% confidence interval (CI), which gives a range of probable values for the estimate (e.g., OR = 1.88, 95% CI 1.30 to 2.73). The width of the CI reflects the precision of an estimate. The narrower the CI, the more precise the estimate. The point estimate and its CI are also collectively known as the interval estimate.

For relative effect estimates, if the point estimate and its CI are greater than 1, the data points to the conclusion that the geometric mean (or odds of prevalence) is higher in the group of people who are exposed than the group of people who are not exposed; conversely, if the point estimate and its CI are below 1, the data points to the conclusion that the geometric mean (or odds of prevalence) is lower in the group of people who are exposed.

The further away from 1, in either direction, the stronger the association. For example, in our models of serum PFAS concentrations in exposed and comparison communities, a ratio of geometric means of 0.5 suggests that the geometric mean of serum PFAS concentrations in an exposed community is half the geometric mean of serum PFAS concentrations in a comparison community (referred to as an 'inverse' association), whereas a ratio of geometric means of 2.0 suggests that the geometric mean of serum PFAS concentrations in an exposed community is twice the geometric mean of serum PFAS concentrations in a comparison community (referred to as a 'positive' association).

If the CI includes 1, the data are compatible with no difference ('no effect') and other possibilities. However, there are three possible interpretations:

1. If the upper and lower limits of the CI are close to 1 (e.g., 0.96 to 1.04), the data points to the conclusion that there is no (meaningful) difference in geometric mean (or odds of prevalence) between the groups of people.
2. If one of the CI limits is close to 1 (e.g., 0.95 to 3.90) geometric mean (or odds of prevalence) are likely different, but too imprecise to confidently conclude there is an effect ('uncertain').
3. If the CI is wide and neither of its limits are close to 1 (e.g., 0.60 to 3.90), we are unable to conclude whether or not geometric mean (or odds of prevalence) are different, and they could range from anywhere between much lower to much higher.

When an absolute difference measure is used rather than a ratio (e.g., mean difference), the reference point of no difference is 0 instead of 1. That is, if the point estimate and its CI are greater than 0, the data are most compatible with the conclusion that the mean is higher in the group of people who are exposed than the group of people who are not exposed; conversely, if the point estimate and its CI are below 0, the data are most compatible with the conclusion that the mean is lower in the group of people who are exposed.

Deviations from original research protocol

During the course of the Blood Serum Study, we made changes to the research that varied from the original protocol published in 2018.[69] These changes included:

- **Inclusion of children:** we proposed to recruit children in the comparison communities, however, this was not feasible due to the small number of child participants in individual PFAS Management Areas. It was also difficult to recruit child participants from comparison communities for the Blood Serum Study.

- **Classification of residents:** we proposed classifying people in exposed communities as either current residents or all other participants. Instead, we classified participants as having ever lived or worked in a PFAS Management Area. We conducted additional analyses including only the data of participants who lived in a PFAS Management Area at the time of blood collection.

- **Expansion of biomarker measurements:** in addition to the biochemical markers of health identified in the PFAS Health Study Systematic Review and defined in the research protocol, we included thyroid and liver function tests, based on research published after the Systematic Review.[63,68,69]

- **Results reporting to participants**: we proposed to report blood test results to participants of the comparison communities soon after a blood sample was taken. However, to ensure there were no systematic differences in the testing of samples from exposed and comparison populations, we tested all samples for biochemical markers of health at the conclusion of the Blood Serum Study. Results were reported to participants at the end of the Study.

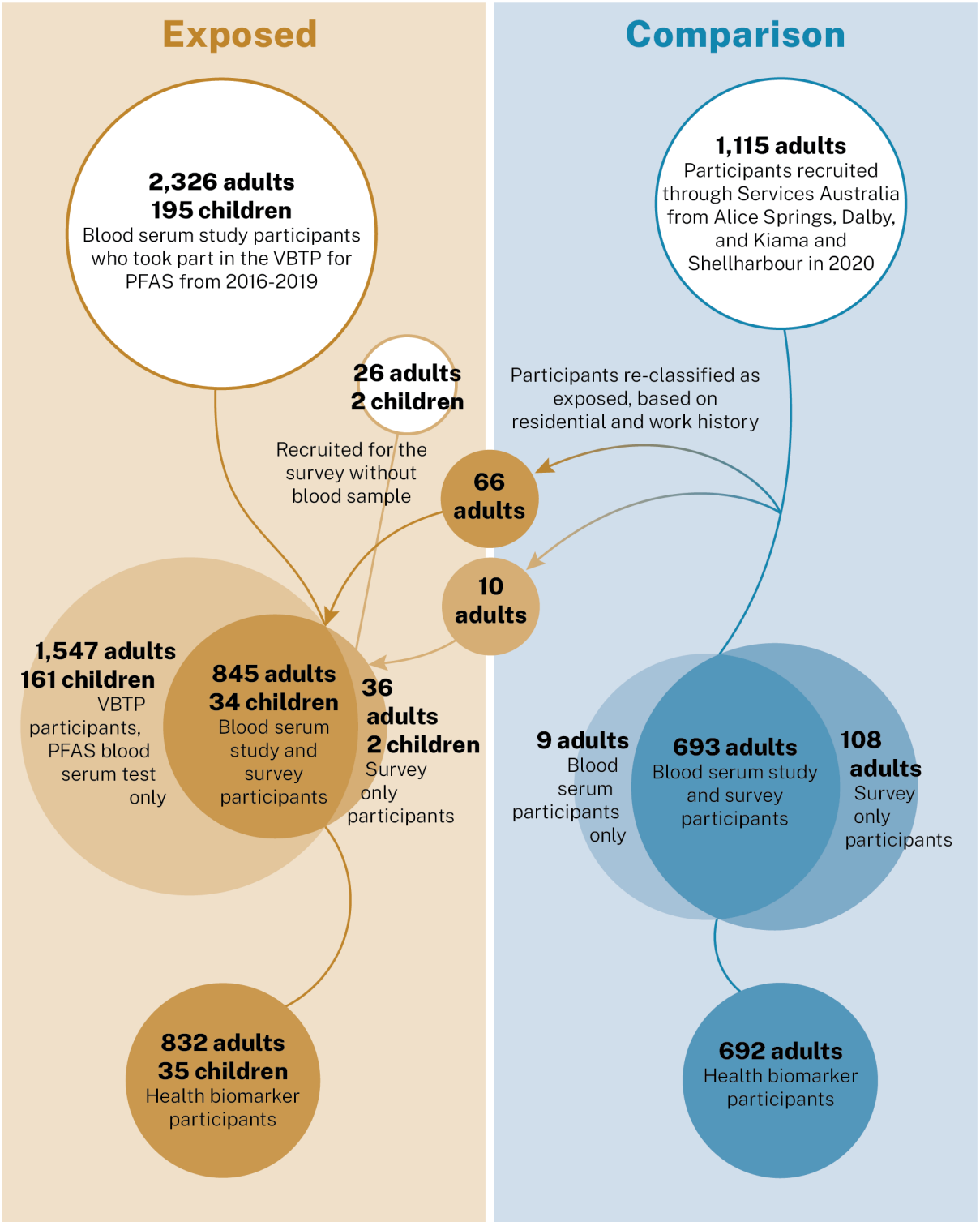
Results

Participation in the Blood Serum Study

Recruitment and study participation for the Blood Serum Study and Cross-sectional Survey is shown in Figure 2. In total, 3,289 children and adults from the exposed and comparison communities participated in the Blood Serum Study from 2016 to 2020. Blood sample collection over the study period is shown in Figure A2-1. We recruited 195 children and 2,326 adults from the PFAS Management Areas in Katherine, Oakey and Williamtown who participated in the VBTP from 2016 to 2019. In addition, we recruited 1,115 adults living in Alice Springs, Dalby or the Kiama and Shellharbour area in 2020. Across the comparison communities, 3% (768/30,000) of residents who were randomly sampled from the Medicare Enrolment File participated in the Blood Serum Study. However, we re-classified 9% (66/768) of these participants from the comparison communities as former residents and/or workers of the PFAS Management Areas, based on data collected in the Cross-sectional Survey.

Overall, 2,587 adults and children from the PFAS Management Areas in Katherine, Oakey and Williamtown participated in the Blood Serum Study. We recruited 38% (981/2,587) of participants from Katherine, 13% (332/2,587) from Oakey and 35% (918/2,587) from Williamtown. In addition, 9% (228/2,587) of participants had lived or worked in two or more of the PFAS Management Areas. We had insufficient data to allocate 5% (128/2,587) of participants to Katherine, Williamtown or Oakey and subsequently, excluded these participants from analyses conducted by location. Across the exposed communities, 34% (879/2,587) of the Blood Serum Study participants also participated in the Cross-sectional Survey in 2019 and 34% (867/2,587) consented to further biomarker testing of their blood sample. Of the 702 adults from Alice Springs, Dalby and Kiama and Shellharbour who participated in the Blood Serum Study, 99% (693/702) participated in the Cross-sectional Survey in 2020 and 99% (692/702) consented to further biomarker testing of their blood sample.

Figure 2. Blood Serum Study and Cross-sectional Survey participation for exposed and comparison populations, 2016–2020.



Participant characteristics

Demographic characteristics of Blood Serum Study participants are shown in Table 3.

Table 3. Demographic characteristics of residents and workers of PFAS Management Areas, 2016–2020, and residents of comparison communities, 2020, who participated in the Blood Serum Study.

	Katherine and Alice Springs, NT		Oakey and Dalby, Qld		Williamtown and Kiama and Shellharbour, NSW	
Characteristic	Ever exposed % (N)	Comparison % (N)	Ever exposed % (N)	Comparison % (N)	Ever exposed % (N)	Comparison % (N)
Total sample†	1,181	171	408	150	1,121	372
Age (years)						
≥15	12% (139)	NA	2% (8)	NA	5% (56)	NA
16–29	11% (131)	6% (10)	6% (26)	<1% (3)	11% (128)	4% (14)
30–49	35% (414)	23% (39)	34% (139)	27% (40)	35% (387)	15% (54)
50–69	34% (403)	56% (95)	44% (181)	50% (74)	38% (426)	50% (184)
≥70	8% (93)	16% (27)	13% (54)	22% (33)	11% (121)	33% (120)
Missing	<1% (1)	0% (0)	0% (0)	0% (0)	<1% (3)	0% (0)
Sex						
Male	50% (593)	40% (67)	69% (282)	43% (65)	65% (726)	42% (157)
Female	50% (587)	61% (104)	31% (126)	57% (85)	35% (395)	58% (215)
Missing	<1% (1)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)
Aboriginal or Torres Strait Islander person						
No	37% (435)	97% (166)	52% (214)	99% (148)	38% (423)	99% (368)
Yes	4% (52)	3% (5)	2% (7)	1% (2)	1% (11)	1% (4)
Missing	59% (694)	0% (0)	46% (187)	0% (0)	61% (687)	0% (0)

† Total sample for ever exposed participants defined as ever living or working in the PFAS Management Area, including participants who have lived or worked across multiple PFAS Management Areas.

N: sample size; NA: not applicable.

We classified 32% (817/2,587) of the Blood Serum Study participants from the exposed communities as current residents at the time of blood sample collection. Based on Australian Bureau of Statistics Census data of population sizes, we estimate 7% (817/11,893) of residents who lived in Katherine, Oakey and Williamtown participated in the Blood Serum Study. However, study participation rates varied across the exposed communities: 29% (256/885) in Williamtown; 7% (472/6,303) in Katherine; and 2% (89/4,705) in Oakey.

Demographic characteristics of the current residents of Katherine, Oakey and Williamtown who participated in the Blood Serum Study are shown in Table A2-1. Based on comparisons with Australian Bureau of Statistics Census data, the characteristics of current residents of the PFAS Management Areas who participated in the Study were not representative of the population of each community, as shown in Table A2-2. The current residents of the PFAS Management Areas recruited for the Study were older than the general population in each community, and in Oakey and Williamtown, there were a lower proportion of males. Further, Aboriginal and Torres Strait Islander persons were underrepresented in the Study, particularly in Katherine where 3% (16/472) of current residents who participated in the Study identified as Aboriginal and/or Torres Strait Islander, compared to 25% (1,601/6,303) of the general population. However, 74% (350/472) of

current residents of Katherine did not report whether they were of Aboriginal and Torres Strait Islander descent in the Study, limiting conclusions regarding participation rates.

Serum PFAS concentrations in Katherine, Oakey and Williamtown

Serum PFAS detection frequencies

Blood Serum PFAS detection frequencies for participants of the Blood Serum Study are shown for each PFAS Management Area in Table 4. We detected serum concentrations of the following PFAS in participants from Katherine, Oakey and Williamtown: PFOS, PFHxS, PFOA, PFNA, PFDA, PFHpA and PFBS. The detection frequency was 99.7% (2,578/2,587) for PFOS, 98.1% (2,537/2,587) for PFHxS and 98.5% (2,547/2,587) for PFOA. We detected serum concentrations of PFNA in 62.4% (1,614/2,587) of participants, and less than 10% of participants had detectable serum concentrations of PFDA, PFHpA and PFBS. No participants from the exposed communities had detectable serum concentrations of PFHxA or 6:2 FTS. Based on a minimum detection frequency of 80% in participants, we analysed serum concentrations of PFOS, PFHxS and PFOA in the Blood Serum Study.

Table 4. Detection frequencies of blood serum PFAS concentrations of residents and workers of PFAS Management Areas, 2016–2020.

	Katherine, NT	Oakey, Qld	Williamtown, NSW
PFAS	Ever exposed % (N)	Ever exposed % (N)	Ever exposed % (N)
Total sample†	1,181	408	1,121
PFOS	99.8% (1,179)	99.8% (407)	99.6% (1,116)
PFOA	97.6% (1,153)	99.0% (404)	99.3% (1,113)
PFHxS	98.3% (1,161)	96.6% (394)	98.5% (1,104)
PFNA	51.7% (611)	70.1% (286)	69.9% (783)
PFDA	2.7% (32)	10.8% (44)	12.9% (144)
PFHpA	0.4% (5)	0.2% (1)	0.7% (8)
PFHxA	0% (0)	0% (0)	0% (0)
PFBS	1.4% (17)	9.6% (39)	12.9% (144)
6:2 FTS	0% (0)	0% (0)	0% (0)

† Total sample for ever exposed participants defined as ever living or working in the PFAS Management Area, including participants who have lived or worked across multiple PFAS Management Areas.

N: sample size.

Summary statistics of serum PFAS concentrations

Box plots of the distributions of blood serum PFOS, PFHxS and PFOA concentrations for participants of the Blood Serum Study are shown for each PFAS Management Area in Figure 3. Geometric means of blood serum PFOS, PFHxS and PFOA concentrations are shown in Figure 4. Additional summary statistics of serum PFOS, PFHxS and PFOA concentrations are shown for each PFAS Management Area in Table A3-1.

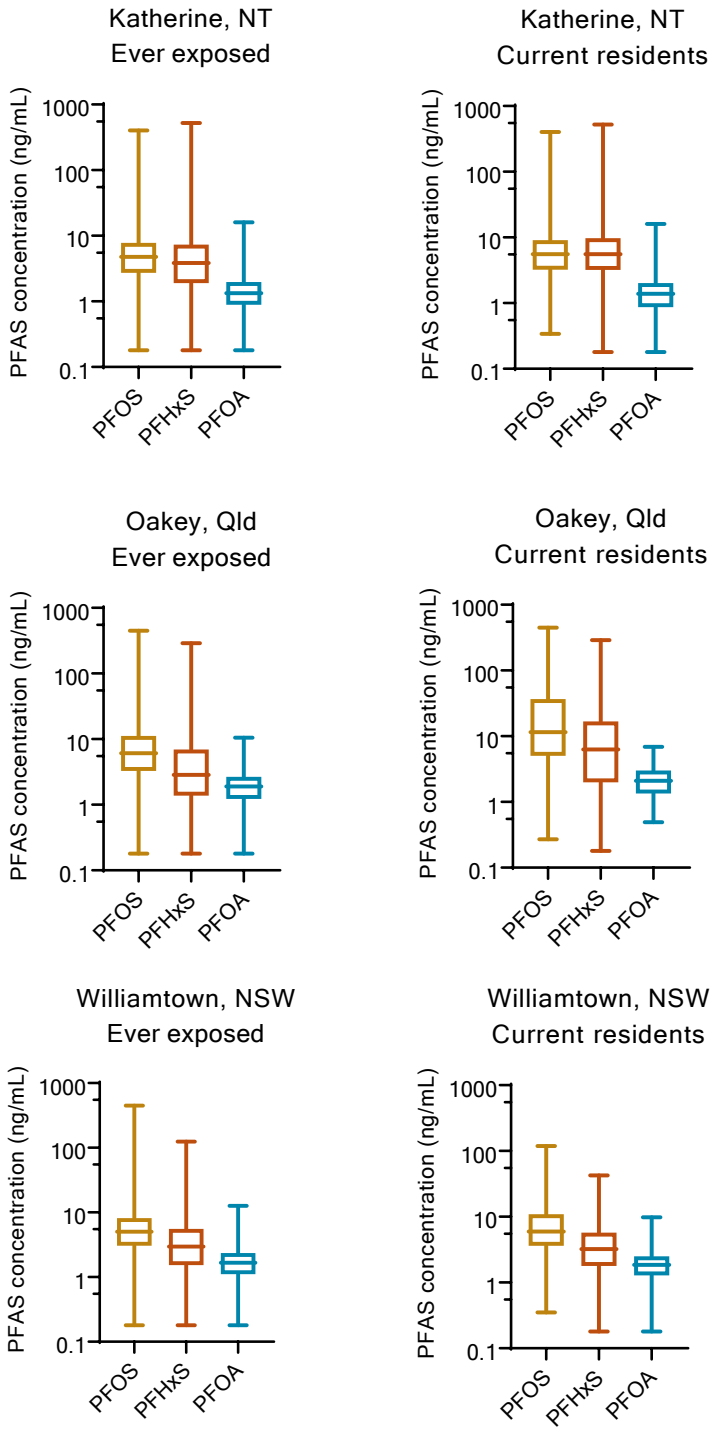
Across Katherine, Oakey and Williamtown, the distributions of serum PFOS, PFHxS and PFOA concentrations were positively skewed among participants of the Blood Serum Study, meaning serum PFAS concentrations were clustered at low values for many participants, however, some participants had high serum PFAS concentrations. For ever exposed participants of the Blood Serum Study, who had ever lived or worked in the PFAS Management Areas, the geometric means

of serum PFOS[5] concentration across Katherine, Oakey and Williamtown ranged from 4.9–6.6 ng/mL. The geometric means of serum PFHxS concentration ranged from 2.9–3.7 ng/mL. An explanation of geometric mean is included in the Glossary. The median serum PFOS concentration for ever exposed participants ranged from 4.8–6.1 ng/mL and the median serum PFHxS concentration ranged from 2.9–3.9 ng/mL. Across Katherine, Oakey and Williamtown, serum PFOS and PFHxS concentrations for ever exposed participants were highly correlated (Spearman's correlation = 0.8). The maximum serum PFOS and PFHxS concentration among ever exposed participants were 447.0 ng/mL and 523.0 ng/mL, respectively. However, 75% of ever exposed participants had a serum PFOS concentration of equal to or less than 8.3 ng/mL and a serum PFHxS concentration of equal to or less than 6.4 ng/mL, showing the skewed distribution of serum concentrations among participants of the Blood Serum Study. Across Katherine, Oakey and Williamtown, serum PFOA concentrations of ever exposed participants were also positively skewed, though to less extent. The maximum serum PFOA concentration among ever exposed participants was 16.1 ng/mL and 75% of ever exposed participants had a serum PFOA concentration of equal to or less than 2.3 ng/mL. The geometric means of serum PFOA concentration for ever exposed participants across Katherine, Oakey and Williamtown ranged from 1.3–1.8 ng/mL and the median serum PFOA concentration ranged from 1.3–1.9 ng/mL. Serum PFOA concentrations were moderately correlated with serum PFOS concentrations Spearman's correlation = 0.6) and serum PFHxS concentrations (Spearman's correlation = 0.4) among ever exposed participants.

Additional summary statistics of serum PFOS, PFHxS and PFOA concentrations of participants who lived or worked in multiple PFAS Management Areas and who could not be assigned to a PFAS Management Area are shown in Table A3-3 and Table A3-4, respectively.

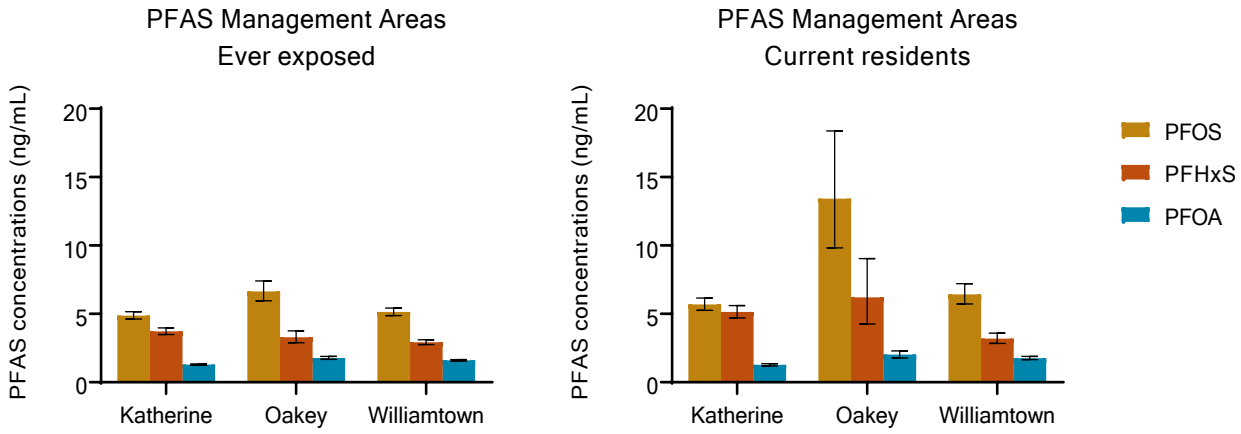
[5] We detected serum concentrations of linear PFOS in 97% (2,403/2,474) of ever exposed participants and branched chain (1-methyl, other-methyl and di-methyl) PFOS concentrations in 96% (2,379/2,474) of participants. Across Katherine, Oakey and Williamtown, the geometric means of serum concentrations ranged from 2.7–2.9 ng/mL for linear PFOS and from 1.8–3.0 ng/mL for branched PFOS (total sum of branched chain). Additional summary statistics for linear and branched serum PFOS concentrations by PFAS Management Area and residence/work status are shown in Table A3-2.

Figure 3. Box plots of the distributions of blood serum PFAS concentrations of residents and workers of PFAS Management Areas by residence/work status, 2016–2020.



The horizontal lines in the middle of the boxes indicate median concentrations, the upper and lower horizontal lines of the boxes are the 25th and 75th percentiles, and the whiskers range between the minimum and maximum serum PFAS concentration. Note that the y axis is on a logarithmic scale. Serum PFAS concentrations of people who have ever lived or worked in the PFAS Management Areas are shown in graph labelled as 'ever exposed' and serum PFAS concentrations of current residents of the PFAS Management Areas are shown in graph labelled as 'current residents'.

Figure 4. Geometric means of blood serum PFAS concentrations of residents and workers of PFAS Management Areas by residence/work status, 2016–2020.



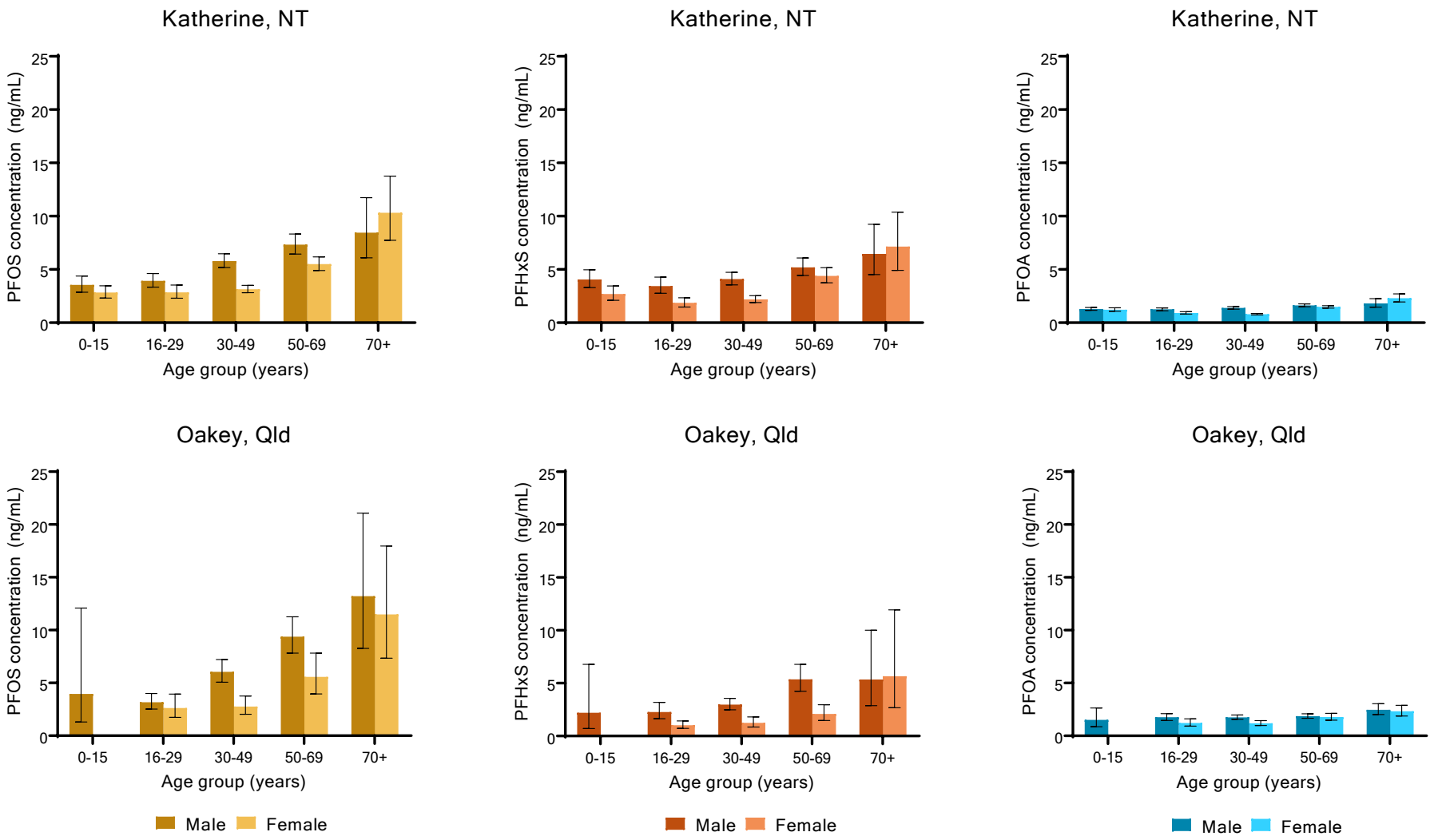
The coloured bars show the geometric mean concentrations and the black error bars represent the 95% confidence intervals (95% CI) for the geometric mean. Serum PFAS concentrations of people who have ever lived or worked in the PFAS Management Areas are shown in graph labelled as 'ever exposed' and serum PFAS concentrations of current residents of the PFAS Management Areas are shown in graph labelled as 'current residents'.

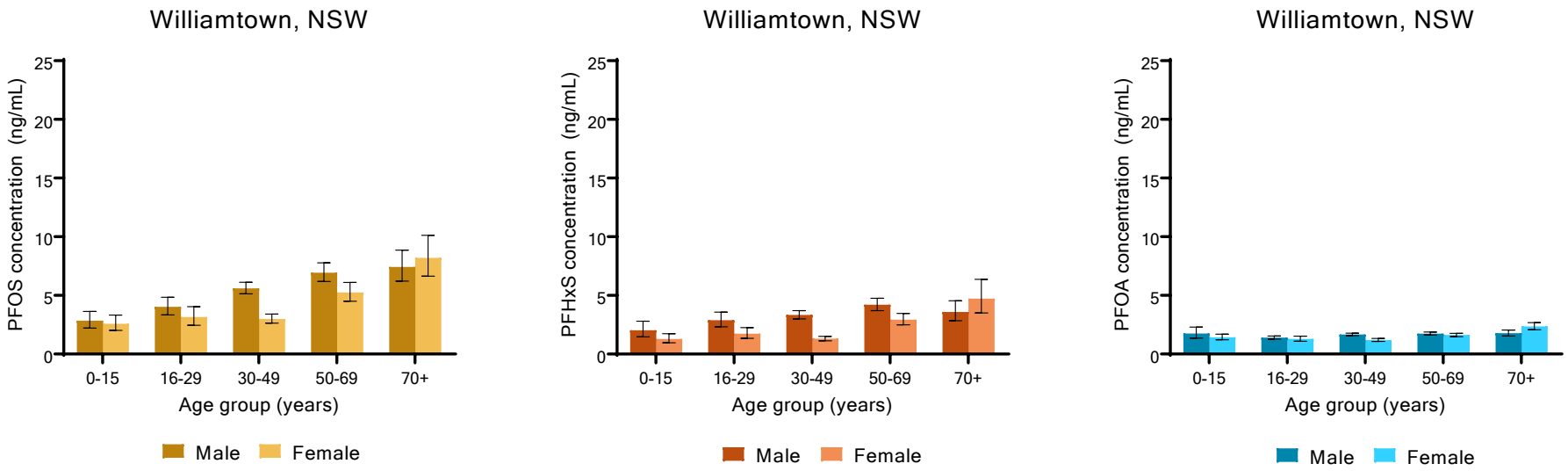
Serum PFAS concentrations by age and sex

The geometric means of serum PFOS, PFHxS and PFOA concentrations by age and sex for ever exposed participants of the Blood Serum Study are shown for each PFAS Management Area in Figure 5. Adjusted ratios of geometric means of blood serum PFOS, PFHxS and PFOA concentrations by age and sex are shown for each PFAS Management Area in Table 5.

Geometric means of serum PFOS, PFHxS and PFOA concentrations were higher in older participants across Katherine, Oakey and Williamtown, and generally lower in females than in males. Compared to ever exposed participants aged 16–29 years old and adjusting for sex, geometric means of serum PFOS concentrations were 25% higher in participants aged 30–49 years old (RoM = 1.25, 95% CI 1.12 to 1.38), 76% higher in participants aged 50–69 years old (RoM = 1.76, 95% CI 1.57 to 1.97), and 132% higher in participants aged ≥70 years old (RoM = 2.32, 95% CI 2.00 to 2.70). Ratios of geometric means were similar for the association of age and serum PFHxS concentrations among ever exposed participants. We observed no material difference in the geometric means of serum PFOS and PFHxS concentrations in ever exposed participants aged ≤15 years old, compared to participants aged 16–29 years old. Ratios of geometric means were lower for PFOA concentrations, with the exception of geometric means of serum PFOA concentrations in ever exposed participants aged ≤15 years old, which were 19% higher (RoM = 1.19, 95% CI 1.08 to 1.32) compared to participants aged 16–29 years old. The association of serum PFAS concentrations and demographic characteristics did not change markedly in a sensitivity analysis using multiple imputation by chained equations to replace serum PFAS concentrations below the limit of quantification, as shown in Table A3-5.

Figure 5. Geometric means of blood serum PFAS concentrations of residents and workers of PFAS Management Areas by age and sex, 2016–2020.





The coloured bars show the geometric means of serum PFAS concentrations and the black error bars represent the 95% confidence intervals for the geometric mean.

Table 5. Adjusted ratios of geometric means of blood serum PFAS concentrations and demographic characteristics for residents and workers of PFAS Management Areas, 2016–2020.

	PFOS	PFHxS	PFOA
PFAS	Ever exposed Adjusted RoM‡ (95% CI)	Ever exposed Adjusted RoM‡ (95% CI)	Ever exposed Adjusted RoM‡ (95% CI)
Total sample†	2,581	2,581	2,581
Age (years)			
≥15	0.92 (0.81,1.04)	1.07 (0.93,1.23)	1.19 (1.08,1.32)
16–29	Reference	Reference	Reference
30–49	1.25 (1.12,1.38)	1.09 (0.97,1.23)	1.04 (0.97,1.11)
50–69	1.76 (1.57,1.97)	1.70 (1.49,1.94)	1.33 (1.24,1.43)
≥70	2.32 (2.00,2.70)	2.03 (1.68,2.45)	1.64 (1.49,1.81)
Sex			
Male	Reference	Reference	Reference
Female	0.73 (0.69,0.77)	0.67 (0.63,0.71)	0.80 (0.77,0.84)

‡ Adjusted for sex or age.

† Total sample for ever exposed participants defined as ever living or working in the PFAS Management Area, including participants who have lived or worked across multiple PFAS Management Areas.

RoM: Ratio of geometric means; CI: confidence interval.

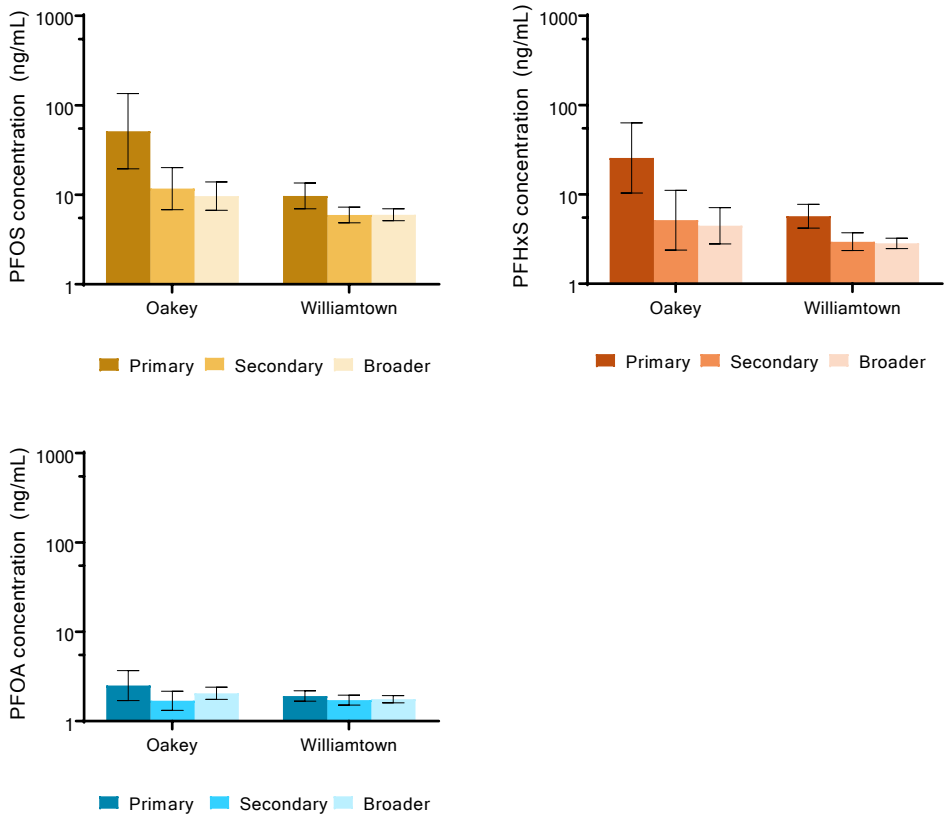
Serum PFAS concentrations by PFAS Management Area Zone

PFAS Management Area Zones in Oakey and Williamtown represent the geospatial distribution of PFAS in the environment. Maps of the PFAS Management Area Zones are available from the Australian Government Department of Defence and the NSW Environment Protection Authority.[50,76] The geospatial distribution of PFAS in the environment was not defined by Zones with distinct boundaries in the Katherine PFAS Management Area; therefore, blood serum PFAS concentrations by Zone were not analysed for Katherine residents. Geometric means of blood serum PFOS, PFHxS and PFOA concentrations by age and sex for current residents of Oakey and Williamtown are shown Figure 6. Additional summary statistics of serum PFAS concentrations by PFAS Management Area Zones for current residents of Oakey and Williamtown are shown in Table A3-6. Adjusted ratios of geometric means of blood serum PFAS concentrations and PFAS Management Area Zones in Oakey and Williamtown are shown in Table A3-7.

Across Oakey and Williamtown, geometric means of serum PFOS and PFHxS concentrations were higher among Blood Serum Study participants who were current residents of the Primary Management Zone, compared to current residents of the Broader Management Zone. In Oakey, the geometric mean of serum PFOS concentrations for the Primary Management Zone was 4.89 (95% CI 1.89 to 12.62) times as high as the Broader Management Zone, after adjusting for age and sex. Similarly, the geometric mean of serum PFHxS concentrations for the Primary Management Zone in Oakey was 5.55 (95% CI 2.14 to 14.39) times that of the Broader Management Zone. Ratios of geometric means for PFOS and PFHxS concentrations were lower in Williamtown. The geometric mean of serum concentrations for the Primary Management Zone in Williamtown was 1.81 (95% CI 1.13 to 2.92) times as high as the Broader Management Zone for PFOS and 2.25 (95% CI 1.56 to 3.23) times as high as the Broader Management Zone for PFHxS. Across Oakey and Williamtown, we observed no material difference in geometric means of PFOS and PFHxS concentrations for current residents of the Secondary Management Zone, compared to current residents of the Broader Management Zone, or geometric means of PFOA concentrations across all Management Zone levels. The association of serum PFAS concentrations and demographic characteristics did

not change markedly in a sensitivity analysis using multiple imputation by chained equations to replace serum PFAS concentrations below the limit of quantification, as shown in Table A3-8.

Figure 6. Geometric means of blood serum PFAS concentrations of current residents of PFAS Management Areas by Zone, 2016–2019.



The coloured bars show the geometric means of serum PFAS concentrations and the black error bars represent the 95% confidence intervals for the geometric mean. Note that the y axis is on a logarithmic scale.

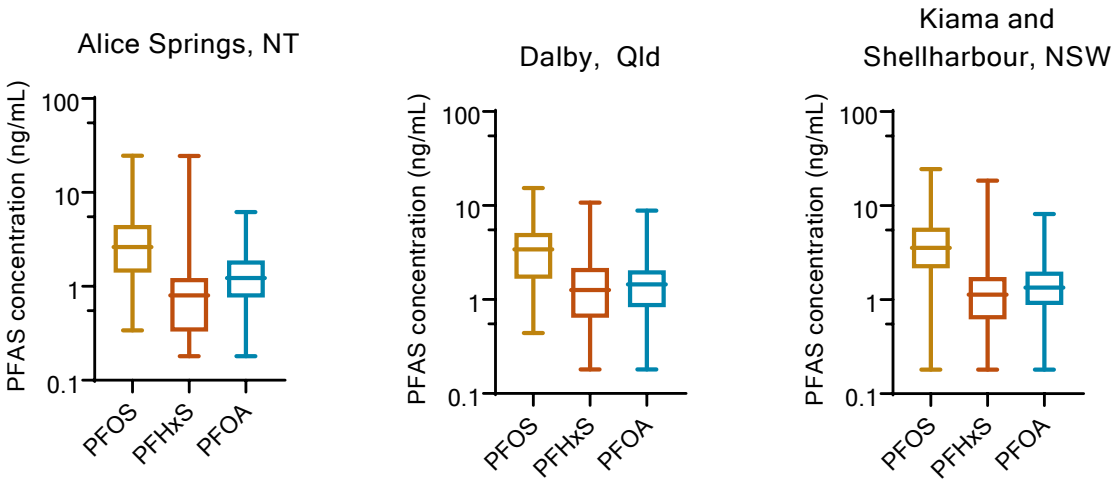
Comparing serum PFAS concentrations in the exposed and comparison communities

Serum PFAS concentrations in Alice Springs, Dalby and Kiama and Shellharbour

Blood Serum PFAS detection frequencies for participants of the Blood Serum Study are shown for each PFAS Management Area in Table A4-1. We detected serum concentrations of the following PFAS in participants from Alice Springs, Dalby and Kiama and Shellharbour: PFOS, PFHxS, PFOA, PFNA, PFDA and PFBS. The detection frequency was 99.6% (689/692) for PFOS, 91.0% (630/692) for PFHxS and 99.1% (686/692) for PFOA.

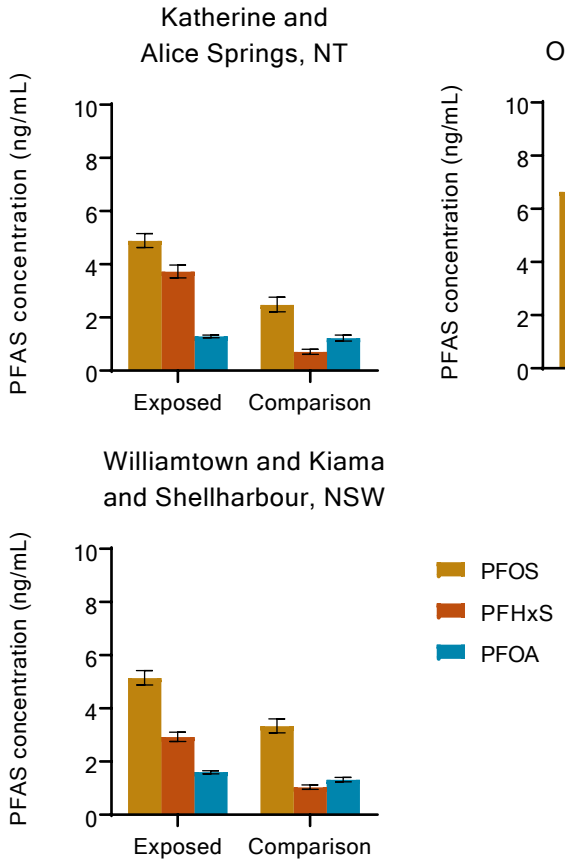
Box plots of the distributions of blood serum PFOS, PFHxS and PFOA concentrations for participants of the Blood Serum Study are shown for each comparison community in Figure 7. Geometric means of blood serum PFOS, PFHxS and PFOA concentrations are shown each exposed and comparison community in Figure 8. Across Alice Springs, Dalby and Kiama and Shellharbour, the geometric means of serum PFOS concentrations among participants for the Blood Serum Study ranged from 2.5–3.3 ng/mL. The geometric means of serum concentrations ranged from 0.7–1.2 ng/mL for PFHxS and from 1.2–1.4 ng/mL for PFOA. Additional summary statistics of serum PFOS, PFHxS and PFOA concentrations are shown for each comparison community in Table A4- 2.

Figure 7. Box plots of the distributions of blood serum PFAS concentrations of residents of comparison communities, 2020.



The horizontal lines in the middle of the boxes indicate median concentrations, the upper and lower horizontal lines of the boxes are the 25th and 75th percentiles, and the whiskers range between the minimum and maximum serum PFAS concentration. Note that the y axis is on a logarithmic scale.

Figure 8. Geometric means of blood serum PFAS concentrations of residents and workers of PFAS Management Areas, 2016–2020, and residents of comparison communities, 2020.



The coloured bars show the geometric mean concentrations and the black error bars represent the 95% confidence intervals for the mean.

Adjusted ratios of geometric means of blood serum PFOS, PFHxS and PFOA concentrations by age and sex are shown for each comparison community in Table A4-3. As we observed for ever exposed participants from Katherine, Oakey and Williamtown, geometric means of serum PFOS, PFHxS and PFOA concentrations were higher in older participants from the comparison communities and lower in females than in males. The association of serum PFAS concentrations and demographic characteristics did not change markedly in a sensitivity analysis using multiple imputation by chained equations to replace serum PFAS concentrations below the limit of quantification, as shown in Table A3-5.

Comparing serum PFAS concentrations across communities

Adjusted ratios of geometric means of blood serum PFOS, PFHxS and PFOA concentrations for Blood Serum Study participants are shown for corresponding exposed and comparison communities in Table 6. Geometric means of serum PFAS concentrations were higher among participants from Katherine, Oakey and Williamtown, compared to participants from Alice Springs, Dalby, and Kiama and Shellharbour, respectively. Across the PFAS Management Areas, geometric mean of serum PFOS concentrations for ever exposed participants were 1.85–2.27 times as high as the comparison communities, after adjusting for age and sex. Ratios of geometric means of serum PFHxS concentrations were higher across the PFAS Management Areas. In Katherine, the geometric mean of serum PFHxS concentrations for ever exposed participants was 5.86 (95% CI 5.08 to 6.75) times that of Alice Springs. In Oakey and Williamtown, the geometric mean of serum PFHxS concentrations for ever exposed participants was 2.47 (95% CI 2.03 to 3.00) and 3.07 (95% CI 2.75 to 3.43) times as high as Dalby and Kiama and Shellharbour, respectively. Comparatively, Ratios of geometric means for serum PFOS and PFHxS were larger for current residents of the PFAS Management Areas. Notably, the geometric mean of serum PFHxS concentrations in current residents of Katherine was 8.29 (95% CI 7.10 to 9.68) that of Alice Springs. Across Katherine, Oakey and Williamtown, geometric means of serum PFOS concentrations for ever exposed participants were 1.16–1.31 times as high as the comparison communities.

Table 6. Adjusted ratios of geometric means of blood serum PFAS concentrations for participants of the exposed and comparison by state and residence/work status, 2016–2020.

	Katherine and Alice Springs, NT		Oakey and Dalby, Qld		Williamtown and Kiama and Shellharbour, NSW	
PFAS	Ever exposed Adjusted RoM‡ (95% CI)	Current resident Adjusted RoM‡ (95% CI)	Ever exposed Adjusted RoM‡ (95% CI)	Current resident Adjusted RoM‡ (95% CI)	Ever exposed Adjusted RoM‡ (95% CI)	Current resident Adjusted RoM‡ (95% CI)
Total sample†	1,211	595	550	236	1,434	207
PFOS	2.27 (2.03,2.54)	2.67 (2.36,3.03)	2.22 (1.90,2.60)#	4.00 (2.77,5.79)#	1.85 (1.65,2.06)	2.41 (2.06,2.83)#
PFHxS	5.86 (5.08,6.75)	8.29 (7.10,9.68)	2.47 (2.03,3.00)	5.07 (3.27,7.86)	3.07 (2.75,3.43)	3.72 (3.17,4.36)
PFOA	1.16 (1.05,1.27)	1.15 (1.03,1.28)	1.30 (1.15,1.47)	1.38 (1.17,1.63)	1.31 (1.22,1.41)	1.50 (1.37,1.65)

‡ Adjusted for sex and age. Age was modelled using a restricted cubic spline with 3 knots.

† Total sample for ever exposed participants defined as ever living or working in the PFAS Management Area, including participants who have lived or worked across multiple PFAS Management Areas.

Estimated assuming an independence (rather than exchangeable) within-cluster correlation structure and cluster-robust standard errors.

RoM: Ratio of geometric means; CI: confidence interval.

Elevated serum PFAS concentrations in Katherine, Oakey and Williamtown

We defined elevated (higher than background level) serum PFOS, PFHxS and PFOA concentrations based on the 95th percentile of serum concentration among Blood Serum Study participants from the comparison communities. The 95th percentiles of PFOS, PFHxS and PFOA concentrations for the comparison communities are shown for three age categories (16–49, 50–69 and ≥70 years old) in Table 7.

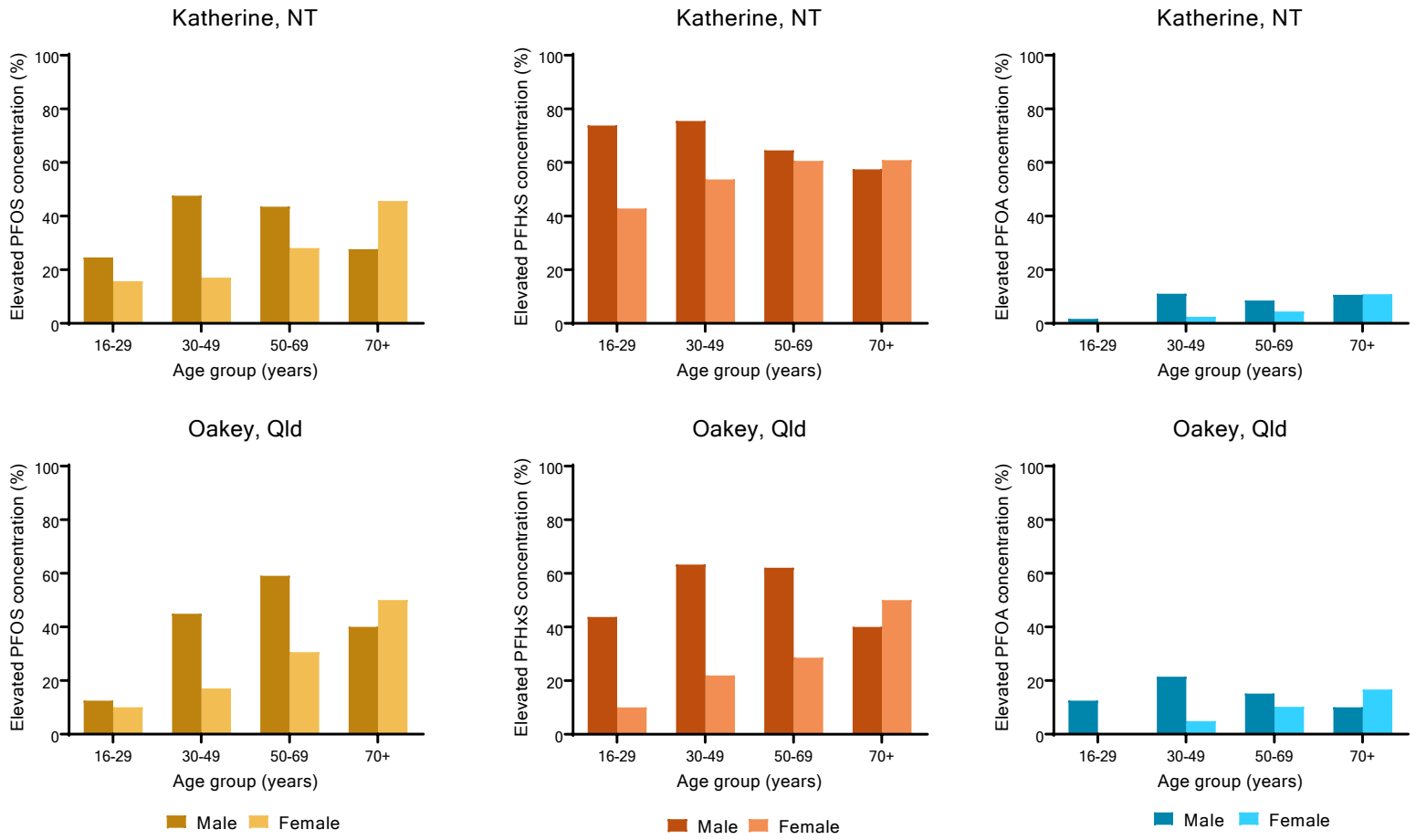
Table 7. 95th percentiles of blood serum PFAS concentrations of residents of the comparison communities by age, 2020.

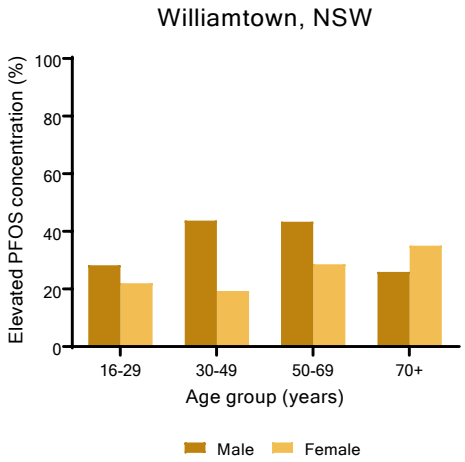
		PFOS	PFHxS	PFOA
	Total sample† N	95th percentile (ng/mL)	95th percentile (ng/mL)	95th percentile (ng/mL)
Age (years)				
16–49	160	5.72	2.21	2.73
50–69	353	7.45	3.84	3.40
≥70	180	11.03	5.34	4.13

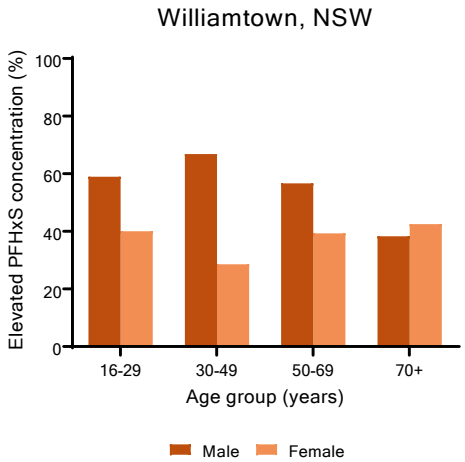
† Total sample was defined as all Blood Serum Study participants from the comparison communities.
N: sample size.

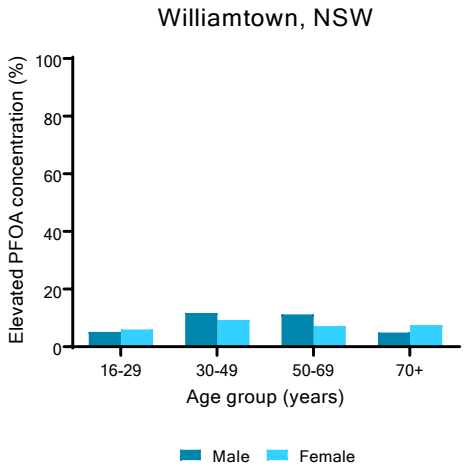
The proportions of participants who had elevated serum PFOS, PFHxS and PFOA concentrations by age and sex are shown for each PFAS Management Area in Figure 9. In Katherine, 29% of ever exposed participants had an elevated serum PFOS concentration and 55% had an elevated serum PFHxS concentration. In Oakey, 42% of ever exposed participants had an elevated serum PFOS concentration and 49% had an elevated serum PFHxS concentration. Similarly, in Williamtown, 33% of ever exposed participants had an elevated serum PFOS concentration and 48% had an elevated serum PFHxS concentration. In contrast, 6–14% of ever exposed participants across the PFAS Management Areas had an elevated serum PFOA concentration.

Figure 9. Proportions of residents and workers of the PFAS Management Areas with elevated serum PFAS concentrations by age and sex, 2016–2020.









The coloured bars show the proportions of residents and workers who had an elevated serum PFAS concentration by age and sex.

Risk factors for elevated serum PFAS concentrations

We conducted our analyses of the risk factors for elevated serum PFAS concentrations with data from the Blood Serum Study and the Cross-sectional Survey, and therefore, excluded people who did not complete both components of the PFAS Health Study. We excluded participants who had worked but not lived in the PFAS Management Areas due to limited information on bore water ingestion and local produce consumption in the workplace, as well as children due to low participation rates and different potential exposure pathways for infants and young children. In this section, we present data on the risk factors for elevated serum PFAS concentration in adult participants who had ever lived in the PFAS Management Areas, referred to as residents of Katherine, Oakey and Williamtown or collectively, as residents of the PFAS Management Areas. As stated earlier, based on comparisons with Australian Bureau of Statistics Census data, the characteristics of current residents of the PFAS Management Areas who participated in the Blood Serum Study were not representative of the general population of each exposed community.

Potential sources of PFAS exposure in Katherine, Oakey and Williamtown

Across Katherine, Oakey and Williamtown, 37% (251/676) of adult residents of the PFAS Management Areas had a bore water supply on their current or previous property. Before notification of the environmental contamination, a high proportion of residents who had a bore water supply reported using the water for consumption or other household activities, such as bathing/showering or outdoor watering. Only 9% (22/251) of residents who had a bore water supply on their property had never used it. In Katherine, 26% (98/372) of residents had a bore water supply that they used, or had previously used, for at least one household activity. Similarly, in Oakey, 32% (51/160) of residents had a bore water supply on their property that they used for at least one household activity. Among residents of Williamtown, 39% (119/309) had a bore water supply that they used for at least one activity. However, fewer participants from Williamtown reported consuming the bore water supply on their property than in Katherine and Oakey. In total, 18% (55/309) of Williamtown residents reported ingesting bore water at least weekly, through drinking, cooking, bathing/showering or swimming. In comparison, 25% (94/372) of residents of Katherine and 28% (45/160) of residents of Oakey reported ingesting bore water at least weekly before notification of the contamination.

Further to bore water use, 54% (366/676) of adult residents of the PFAS Management Areas consumed locally grown produce classified as high-risk in the Human Health Risk Assessments, according to the concentrations of PFAS measured in each type of food.[50-52]. In Katherine, 51% (189/372) of residents consumed high-risk local produce, including eggs, fish, shellfish and crustaceans, at least weekly before notification of the contamination. In Oakey, high-risk local produce included eggs, fish, fruit and vegetables, and livestock, which 42% (67/160) of residents consumed at least weekly before notification of the contamination. In Williamtown, 61% (187/309) of residents consumed high-risk local produce, including eggs, fruit and vegetables, and livestock, at least weekly before notification of the contamination.

Across Katherine, Oakey and Williamtown, adult residents of the PFAS Management Areas reported exposure to AFFF in their workplace (occupational) and in their community or household. Overall, 24% (164/676) of residents reported occupational exposure to AFFF and 11% (73/676) reported community or household exposure to AFFF, primarily during celebrations where the foam was used for entertainment purposes. Of the residents who were exposed to AFFF in their workplace, 27% (44/164) were current or former firefighters, 23% (37/164) described exposure through annual firefighting training and 38% (62/164) reported general exposure through firefighting training of an unspecified frequency (less than weekly). An additional 11% (18/164) of residents who were exposed to AFFF in their workplace reported infrequent or accidental

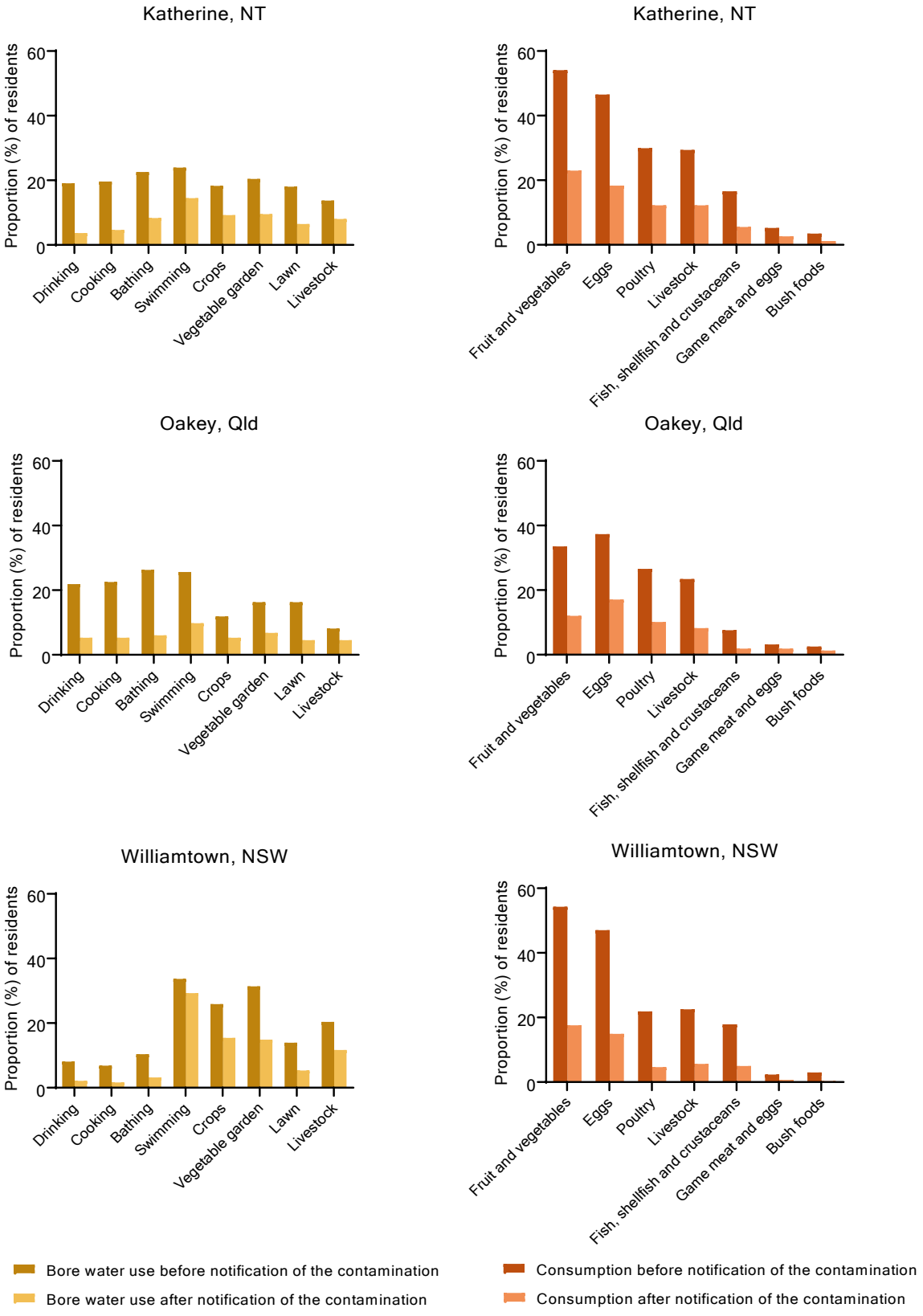
exposure, for example during servicing or testing of equipment, or during an incident. In total, 37% (60/164) of the occupational-exposed residents reported at least weekly use of AFFF; 45% (27/60) of these participants were current or former firefighters. At the time of survey completion, 12% (19/164) of the occupational-exposed residents reported ongoing exposure to AFFF products.

Changes in behaviour after notification of the environmental contamination

Bore water uses and local produce consumption before and after notification of the environmental contamination for adult residents who participated in the Blood Serum Study and Cross-sectional Survey are shown for each PFAS Management Area in Figure 10. Among residents who had ever had a bore water supply on their property that they used for household activities, and who had not moved out prior to notification of the contamination, 18% (25/139) ceased using bore water for all household activities after notification of the environmental contamination in the PFAS Management Areas. Further, 60% (84/139) reported reducing their use of bore water after notification of the contamination by using their bore water supply for some, but not all, of the household activities for which they had previously used it. In Katherine, 8% (4/52) of residents ceased bore water use for all household activities and 63% (33/52) reduced the household activities for which they used bore water, while in Oakey, 12% (3/25) of residents ceased bore water use for all activities and 48% (12/25) used bore water for some, but not all, activities after notification of the contamination. Comparatively, a higher proportion of residents from Williamtown reduced their use of bore water after notification of the contamination; 24% (19/80) ceased bore water use for all activities and 61% (49/80) reduced the household activities for which they used bore water.

Following notification of the contamination, 35% (152/432) of residents who were living in the PFAS Management Areas changed their local produce consumption. Overall, 37% (83/226) of Katherine residents, 41% (77/188) of Williamtown residents and 17% (17/99) of Oakey residents, made changes to their consumption of local produce from the PFAS Management Areas.

Figure 10. Bore water use and local produce consumption before and after notification of the environmental contamination for residents of the PFAS Management Areas, 2019–2020.



The coloured bars show the proportion of residents who consumed bore water or local produce.

Risk factors for elevated serum PFAS concentrations in Katherine, Oakey and Williamtown

The proportions of adult residents who had elevated blood serum PFOS, PFHxS and PFOA concentrations, among participants of the Blood Serum Study and Cross-sectional Survey, are shown for each PFAS Management Area in Table 8. Odds ratios for elevated blood serum PFOS, PFHxS and PFOA concentrations in relation to exposure to the risk factors of interest for adult residents of Katherine, Oakey and Williamtown are also shown in Table 8. Secondary and sensitivity analyses of elevated level blood serum PFOS, PFHxS and PFOA concentrations for Katherine, Oakey and Williamtown are included in Appendix 5.

We observed associations between elevated PFOS and PFHxS concentrations and frequent consumption of bore water and high-risk produce, occupational exposure to AFFF and length of residence in at least one PFAS Management Area. With few exceptions, crude and adjusted estimates showed an effect in the same direction across all three communities, compatible with an association between exposure to the risk factors assessed in this analysis and a higher odds of elevated serum PFOS and PFHxS concentrations. However, we are uncertain about some of the estimates due to their wide confidence intervals and effects in the opposite direction, or null effects, are also compatible with our data and models.

Among adult residents from Oakey, our data (given our model assumptions) were compatible with a higher odds of elevated serum PFOS concentrations with frequent (at least weekly) ingestion of bore water (OR = 2.66, 95% CI 1.28 to 5.52). Estimates were similar for elevated serum PFHxS concentrations (OR = 2.69, 95% CI 1.26 to 5.73) and frequent ingestion of bore water in Oakey. Estimates for bore water ingestion did not change markedly across sensitivity analyses, including when we expanded the definition of bore water use to include potential pathways of dermal exposure to PFAS, as shown in Appendix 5. An exception was elevated serum PFOS and PFHxS concentrations when we excluded participants who had not resided in Oakey within 5 and 15 years of the survey; however, estimates did not change markedly when we excluded participants who had not resided in Oakey within 10 years of the survey.

In Williamtown, our data were compatible with no material difference in the odds of elevated serum PFOS and PFHxS concentrations among adult residents who frequently ingested bore water and those who infrequently (including never) ingested bore water. However, we observed an association between frequent consumption of high-risk locally grown produce (including eggs, livestock, and fruit and vegetables) and a higher odds of elevated serum PFOS (OR = 1.81, 95% C 1.01 to 3.24) and serum PFHxS (OR = 2.02, 95% CI 1.18 to 3.45) concentrations, among adult residents of the PFAS Management Area. Further, our data were compatible with a higher odds of elevated serum PFHxS concentrations associated with occupational exposure to AFFF (OR = 2.15, 95% CI 1.09 to 4.25) among adult residents of Williamtown. Estimates of consumption of high-risk local produce and occupational AFFF exposure did not change markedly across sensitivity analyses, as shown in Appendix 5. An exception was elevated serum PFOS and PFHxS concentrations when we excluded participants who had not resided in Williamtown within 5 years of the survey, where our estimates of both consumption of high-risk local produce and occupational AFFF exposure were attenuated.

Among adult residents of Williamtown, we observed associations between living in the PFAS Management Area for more than 16 years (the highest tertile of residence length among participants) and a higher odds of elevated serum PFOS (OR = 2.71, 95% CI 1.21 to 6.08) and serum PFHxS (OR = 2.07, 95% CI 0.96 to 4.44) concentrations. Similarly, in Katherine, we observed a higher odds of elevated PFOS (OR = 2.70, 95% CI 1.30 to 5.63) and PFHxS (OR = 8.14, 95% CI 3.14 to 21.12) concentrations in participants who lived in the PFAS Management Area for more than 16 years, compared to participants who lived in the PFAS Management Area for less than 7 years. However, our data were not compatible with an association of elevated serum PFOS or PFHxS

concentrations and length of residence in Oakey. The results of the analyses of length of residence did not change markedly across sensitivity analyses, as shown in Appendix 5. An exception was elevated serum PFOS and PFHxS concentrations when we excluded participants who had not resided in Katherine and Williamtown within 10 years of the survey.

Across analyses, our data were compatible with no material difference in the odds of an adult resident having an elevated serum PFOA concentration for any of the risk factors that we assessed across Katherine, Oakey and Williamtown, with the exception of a higher odds of elevated serum PFOA (OR = 2.91, 95% CI 1.03 to 8.23) concentrations among residents from Williamtown who frequently consumed high-risk local produce. As observed for other assessed risk factors, estimates of high-risk local produce consumption did not change markedly across sensitivity analyses, except when we excluded participants who had not resided in Williamtown within 5 and 10 years of the survey.

Adjusted ratios of geometric means of blood serum PFOS, PFHxS and PFOA concentrations and the risk factors that we assessed in residents of Katherine, Oakey and Williamtown are shown in Table A5-9. Results from the analyses of continuous serum PFAS concentrations and risk factors of exposure to PFAS were consistent with our analyses of elevated serum PFAS concentrations. However, ratios of geometric means of serum PFAS concentrations were small for some of the assessed risk factors. In Oakey, the geometric mean of serum PFOS concentrations of residents who frequently consumed bore water was 40% (RoM = 1.40, 95% CI 0.96 to 2.04) higher than residents who infrequently consumed bore water. The geometric mean of serum PFHxS concentrations of Oakey residents who frequently consumed bore water was 75% (RoM = 1.75, 95% CI 1.18 to 2.59) higher than residents who infrequently consumed bore water. In Williamtown, the geometric means of serum PFOS and PFHxS concentrations of residents who frequently consumed high-risk local produce were 22% (RoM = 1.22, 95% CI 1.00 to 1.51) and 18% (RoM = 1.18, 95% CI 0.92 to 1.51) higher than residents who infrequently consumed high-risk local produce, respectively. The geometric mean of serum PFHxS concentrations among residents from Williamtown who reported occupational exposure to AFFF was 59% (RoM = 1.59, 95% CI 1.20 to 2.10) higher than residents who had never been exposed to AFFF in their workplace and their household or community. In Katherine and Williamtown, geometric means of serum PFOS concentrations for residents who had lived in the PFAS Management Areas for more than 16 years were 60% (RoM = 1.60, 95% CI 1.17 to 2.19) and 46% (RoM = 1.46, 95% CI 1.03 to 2.06) higher than residents of less than 7 years, respectively. However, the geometric mean of serum PFHxS concentrations of residents who had lived in Katherine for more than 16 years was 209% higher (RoM = 3.09, 95% CI 2.06 to 4.61).

Table 8. Crude and adjusted odds ratios of elevated blood serum PFAS concentrations in relation to risk factors of exposure to PFAS for adult residents of PFAS Management Areas, 2016–2020.

	Katherine, NT			Oakey, Qld			Williamtown, NSW		
Risk factor	Elevated level % (N/total)	Crude OR (95% CI)	Adjusted OR‡ (95% CI)	Elevated level % (N/total)	Crude OR (95% CI)	Adjusted OR‡ (95% CI)	Elevated level % (N/total)	Crude OR (95% CI)	Adjusted OR‡ (95% CI)
Total sample†		327	327		149	149		287	287
PFOS									
Ingestion of bore water									
Infrequent or never	33% (83/252)	Reference	Reference	31% (35/112)	Reference	Reference	34% (82/242)	Reference	Reference
Frequent	40% (33/83)	1.36 (0.80,2.30)	1.26 (0.70,2.25)	58% (25/43)	3.06 (1.51,6.20)	2.66 (1.28,5.52)	33% (18/55)	0.97 (0.51,1.84)	0.88 (0.45,1.72)
Consumption of high-risk local produce									
Infrequent or never	29% (46/161)	Reference	Reference	34% (30/89)	Reference	Reference	25% (28/113)	Reference	Reference
Frequent	40% (69/173)	1.61 (1.01,2.57)	1.33 (0.78,2.26)	45% (29/65)	1.59 (0.82,3.09)	1.67 (0.77,3.61)	39% (71/183)	1.86 (1.11,3.12)	1.81 (1.01,3.24)
Exposure to AFFF									
Never	31% (63/202)	Reference	Reference	32% (28/88)	Reference	Reference	28% (51/183)	Reference	Reference
Community or household exposure	37% (19/51)	1.39 (0.72,2.67)	1.06 (0.51,2.20)	23% (3/13)	0.65 (0.16,2.57)	0.55 (0.16,1.87)	42% (8/19)	2.26 (0.80,6.39)	2.42 (0.93,6.26)
Occupational exposure	41% (33/80)	1.59 (0.95,2.66)	1.17 (0.63,2.18)	53% (28/53)	2.44 (1.21,4.92)	2.17 (0.87,5.40)	43% (40/94)	2.16 (1.27,3.69)	1.89 (0.94,3.77)
Residence in PFAS Management Area									
<7 years	29% (32/110)	Reference	Reference	35% (24/68)	Reference	Reference	28% (27/97)	Reference	Reference
7–16 years	30% (38/127)	1.02 (0.58,1.78)	1.08 (0.59,1.98)	43% (18/42)	1.39 (0.63,3.04)	1.40 (0.60,3.30)	30% (31/105)	1.11 (0.58,2.10)	1.09 (0.56,2.15)
>16 years	47% (44/94)	2.05 (1.14,3.70)	2.70 (1.30,5.63)	43% (17/40)	1.39 (0.61,3.16)	1.39 (0.52,3.72)	44% (38/87)	2.01 (1.06,3.83)	2.71 (1.21,6.08)

Risk factor	Katherine, NT			Oakey, Qld			Williamtown, NSW		
	Elevated level % (N/total)	Crude OR (95% CI)	Adjusted OR‡ (95% CI)	Elevated level % (N/total)	Crude OR (95% CI)	Adjusted OR‡ (95% CI)	Elevated level % (N/total)	Crude OR (95% CI)	Adjusted OR‡ (95% CI)
PFHxS									
Ingestion of bore water									
Infrequent or never	57% (144/252)	Reference	Reference	39% (44/112)	Reference	Reference	28% (119/242)	Reference	Reference
Frequent	63% (52/83)	1.21 (0.73,2.01)	1.12 (0.65,1.94)	65% (28/43)	2.44 (1.12,5.31)	2.69 (1.26,5.73)	38% (21/55)	0.61 (0.34,1.10)	0.60 (0.31,1.18)
Consumption of high-risk local produce									
Infrequent or never	54% (87/161)	Reference	Reference	43% (38/89)	Reference	Reference	39% (44/113)	Reference	Reference
Frequent	62% (108/173)	1.31 (0.85,2.04)	0.80 (0.44,1.44)	51% (33/65)	1.41 (0.76,2.62)	1.88 (0.90,3.92)	52% (95/183)	1.65 (1.05,2.60)	2.02 (1.18,3.45)
Exposure to AFFF									
Never	54% (109/202)	Reference	Reference	41% (36/88)	Reference	Reference	38% (69/183)	Reference	Reference
Community or household exposure	65% (33/51)	1.49 (0.80,2.77)	0.96 (0.45,2.05)	31% (4/13)	0.64 (0.18,2.25)	0.66 (0.19,2.22)	53% (10/19)	2.00 (0.74,5.39)	2.23 (0.87,5.74)
Occupational exposure	66% (53/80)	1.90 (1.07,3.37)	1.86 (0.83,4.16)	58% (31/53)	1.88 (0.95,3.72)	1.01 (0.48,2.14)	64% (60/94)	2.98 (1.78,4.98)	2.15 (1.09,4.25)
Residence in PFAS Management Area									
<7 years	44% (48/110)	Reference	Reference	47% (32/68)	Reference	Reference	46% (45/97)	Reference	Reference
7–16 years	57% (72/127)	1.61 (0.90,2.89)	2.09 (1.10,3.97)	48% (20/42)	0.90 (0.36,2.21)	0.73 (0.29,1.86)	45% (47/105)	0.94 (0.53,1.66)	0.93 (0.51,1.72)
>16 years	78% (73/94)	4.26 (2.14,8.48)	8.14 (3.14,21.12)	48% (19/40)	1.07 (0.47,2.45)	1.28 (0.51,3.25)	51% (44/87)	1.18 (0.65,2.17)	2.07 (0.96,4.44)
PFOA									
Ingestion of bore water									
Infrequent or never	7% (17/252)	Reference	Reference	9% (10/112)	Reference	Reference	83% (20/242)	Reference	Reference

Risk factor	Katherine, NT			Oakey, Qld			Williamtown, NSW		
	Elevated level % (N/total)	Crude OR (95% CI)	Adjusted OR‡ (95% CI)	Elevated level % (N/total)	Crude OR (95% CI)	Adjusted OR‡ (95% CI)	Elevated level % (N/total)	Crude OR (95% CI)	Adjusted OR‡ (95% CI)
Frequent	7% (6/83)	1.06 (0.41,2.78)	1.21 (0.41,3.56)	12% (5/43)	1.78 (0.71,4.46)	1.86 (0.64,5.39)	7% (4/55)	0.86 (0.28,2.66)	1.31 (0.40,4.30)
Consumption of high-risk local produce									
Infrequent or never	5% (8/161)	Reference	Reference	9% (8/89)	Reference	Reference	5% (6/113)	Reference	Reference
Frequent	8% (14/173)	1.76 (0.72,4.33)	1.85 (0.63,5.44)	9% (6/65)	0.91 (0.31,2.68)	0.92 (0.31,2.67)	9% (17/183)	1.82 (0.70,4.78)	2.91 (1.03,8.23)
Exposure to AFFF									
Never	5% (11/202)	Reference	Reference	9% (8/88)	Reference	Reference	5% (9/183)	Reference	Reference
Community or household exposure	4% (2/51)	0.67 (0.14,3.22)	0.64 (0.15,2.75)	8% (1/13)	0.83 (0.10,7.23)	0.79 (0.09,7.16)	5% (1/19)	1.07 (0.13,8.97)	0.66 (0.07,5.84)
Occupational exposure	11% (9/80)	2.14 (0.85,5.36)	0.87 (0.24,3.13)	9% (5/53)	1.16 (0.38,3.54)	0.85 (0.19,3.80)	14% (13/94)	3.08 (1.27,7.49)	1.69 (0.58,4.93)
Residence in PFAS Management Area									
<7 years	5% (6/110)	Reference	Reference	13% (9/68)	Reference	Reference	10% (10/97)	Reference	Reference
7–16 years	8% (10/127)	1.50 (0.53,4.22)	1.39 (0.36,5.42)	7% (3/42)	0.49 (0.13,1.87)	0.50 (0.14,1.78)	9% (9/105)	0.82 (0.32,2.12)	0.78 (0.28,2.21)
>16 years	5% (5/94)	1.00 (0.30,3.34)	1.24 (0.24,6.35)	8% (3/40)	0.52 (0.14,1.98)	0.45 (0.11,1.95)	5% (4/87)	0.42 (0.13,1.38)	0.50 (0.12,2.06)

Effects are odds ratios of elevated blood serum PFAS concentrations in exposed communities for each of the assessed risk factors.

‡ Adjusted for age, sex, living in multiple PFAS Management Areas and all risk factors assessed in the model. Age was modelled using a restricted cubic spline with 3 knots.

† Total sample for adult residents who participated in the Blood Serum Study and Cross-sectional Survey, defined as ever living in the PFAS Management Area and including participants who have lived across multiple PFAS Management Areas.

N: sample size; OR: odds ratio.

Biochemical markers of health

Crude prevalence of adverse biochemical marker concentrations for participants from the exposed communities are presented for each PFAS Management Area in Table A6-1. Lipid biomarker concentrations outside reference interval ranges were most common in both exposed and comparison communities (e.g., high total cholesterol crude prevalence ranged from 32% to 35%). Few participants had low serum albumin or abnormal TSH concentrations (crude prevalence <4%). Mean biomarker concentrations were similar across exposed communities. Summary statistics of biochemical marker concentrations are presented for each PFAS Management Area in Table A6-2.

Serum lipid concentrations

In Williamtown, we observed higher prevalence of elevated total cholesterol per doubling in PFAS serum concentrations (e.g., total cholesterol (PFOS total) PR = 1.13, 95% CI 1.02 to 1.26), as shown in Table 9. This was also the case for PFOA and both high LDL cholesterol (PR = 1.36, 95% CI 1.03 to 1.80) and the ratio of total cholesterol to HDL cholesterol (PR = 1.26, 95% CI 1.00 to 1.60). The evidence for positive associations was substantially weaker for the remaining PFAS and prevalence of adverse serum lipid concentrations in Williamtown and between all serum PFAS and lipid concentrations in Katherine and Oakey (e.g., high LDL cholesterol: Katherine (PFOA) PR = 1.10, 95% CI 0.72 to 1.67; Oakey (PFOA) PR=0.89, 95% CI 0.66 to 1.22).

We observed higher mean total cholesterol, LDL cholesterol and the total to HDL cholesterol ratio per doubling in some PFAS serum concentrations in Williamtown (e.g., total cholesterol (PFOS total) difference = 0.11 mmol/L, 95% CI 0.02 to 0.19); however, all estimated differences in mean lipid biomarker concentrations were close to zero and mostly not in a consistent direction across communities, as shown in Table 10. The findings from the analyses of lipid function biomarkers did not change markedly in sensitivity analyses, as shown in Table A6-3 to Table A6-24.

Kidney function biomarkers

In Katherine and Williamtown, higher prevalence of elevated urate (uric acid) per doubling in all PFAS serum concentrations was most compatible with our data under our assumed models (e.g., Katherine (PFOA) PR = 1.72, 95% CI 0.98 to 3.03; Williamtown (PFOA) PR = 1.99, 95% CI 1.25 to 3.17), as shown in Table 9. This was also the case for elevated serum creatinine per doubling in PFOA serum concentrations in Williamtown (PR = 1.74, 95% CI 1.31 to 2.32). Prevalence ratios of adverse kidney function biomarker concentrations in all other cases were imprecisely estimated and uninformative with regard to the presence or absence of associations.

Differences in mean serum urate, serum creatinine and the eGFR per doubling in PFAS serum concentrations were small in magnitude (largest difference estimated: serum urate (PFOA) difference = 0.02 mmol/L, 95% CI 0.01 to 0.03; serum creatinine (PFOA) difference = −0.86 umol/L, 95% CI −4.60 to 2.87; eGFR (PFOS total) difference = −1.07 ml/min/1.73 m^2, 95% CI −2.92 to 0.77), as shown in Table 10.

The findings from the analyses of kidney function biomarkers did not change markedly in sensitivity analyses, as shown in Table A6-3 to Table A6-24. An exception was elevated prevalence ratios in Oakey when we excluded past workers and residents who had not resided in Oakey within 10 years of the survey (Table A6-13); however, this was based on a small number of cases of abnormal kidney function biomarkers in that analysis (4 to 7 participants only).

Liver function biomarkers

The estimated prevalence ratios for elevated liver function biomarkers per doubling in PFAS serum concentrations were mostly inconsistent in direction and magnitude across communities, as can

be seen in Table 9. We had some evidence to suggest higher prevalence of elevated ALT, GGT and ALP in Williamtown with higher serum PFAS concentrations (e.g., ALT (PFOS total) PR = 1.46, 95% CI 1.02 to 2.09); however, the prevalence ratios in Katherine and Oakey gave little support to the observations in Williamtown. Differences in mean ALT, AST, ALP, GGT, total protein and serum albumin per doubling in PFAS serum concentrations were small, imprecisely estimated and largely uninformative as to the presence or absence of associations, as shown in Table 10. The findings from the analyses of liver function biomarkers did not change markedly in sensitivity analyses, as shown in Table A6-3 to Table A6-24. An exception was when we imputed missing values in confounders, prevalence ratios for liver function biomarkers were mostly attenuated in Williamtown, as shown in Table A6-19.

Thyroid function biomarkers

In Oakey, based on only a low number of cases of abnormal TSH concentrations, higher prevalence of abnormal TSH concentrations (outside of the reference interval) per doubling in PFOA serum concentrations (PR = 4.49, 95% CI 1.69 to 11.94) and lower prevalence of abnormal TSH concentrations per doubling in other PFAS serum concentrations (e.g., PFHxS PR = 0.55, 95% CI 0.39 to 0.78) were compatible with our data under our assumed models, as can be seen in Table 9. The magnitude and direction of these associations was not consistent with our results in Williamtown (e.g., PFHxS PR = 1.25, 95% CI 0.93 to 1.69; PFOA PR = 0.84, 95% CI 0.46 to 1.53).

Estimates of differences in mean TSH, free T3 and free T4 values per doubling in PFAS serum concentrations were very small in magnitude (close to zero) across all PFAS and communities, as shown in Table 10. The findings from the analyses of thyroid function biomarkers did not change markedly in sensitivity analyses, as shown in Table A6-3 to Table A6-24.

Table 9. Adjusted prevalence ratios of adverse lipid, liver, kidney and thyroid function biomarker concentrations per doubling in PFAS serum concentrations for residents and workers of PFAS Management Areas, 2016–2020.

	Katherine, NT		Oakey, Qld		Williamtown, NSW	
	N (cases) Exposed	Adjusted PR† (95% CI)	N (cases) Exposed	Adjusted PR† (95% CI)	N (cases) Exposed	Adjusted PR† (95% CI)
High total cholesterol (>5.5 mmol/L)						
PFOS (total)	250 (91)	1.04 (0.94,1.16)	153 (49)	1.06 (0.92,1.22)	277 (99)	1.13 (1.02,1.26)
PFOS (branched isomers)	250 (91)	1.01 (0.89,1.15)	150 (49)	1.03 (0.85,1.26)	255 (89)	1.18 (1.05,1.33)
PFOA	250 (91)	1.14 (0.93,1.38)	153 (49)	1.03 (0.81,1.32)	277 (99)	1.31 (1.10,1.56)
PFHxS	250 (91)	1.00 (0.91,1.09)	153 (49)	1.06 (0.93,1.20)	277 (99)	1.16 (1.05,1.27)
Low HDL cholesterol^						
PFOS (total)	250 (32)	0.87 (0.66,1.13)	153 (14)	0.82 (0.53,1.29)	277 (25)	0.90 (0.63,1.30)
PFOS (branched isomers)	250 (32)	0.94 (0.71,1.25)	150 (13)	0.86 (0.53,1.39)	255 (24)	1.22 (0.85,1.74)
PFOA	250 (32)	0.79 (0.54,1.17)	153 (14)	0.96 (0.58,1.60)	277 (25)	1.01 (0.62,1.64)
PFHxS	250 (32)	0.86 (0.73,1.02)	153 (14)	1.03 (0.76,1.38)	277 (25)	1.00 (0.82,1.23)
High LDL cholesterol (>4 mmol/L)						
PFOS (total)	234 (36)	0.99 (0.78,1.25)	153 (19)	1.01 (0.79,1.28)	272 (40)	1.03 (0.87,1.23)
PFOS (branched isomers)	234 (36)	0.93 (0.71,1.22)	150 (19)	1.04 (0.80,1.36)	250 (34)	1.07 (0.87,1.31)
PFOA	234 (36)	1.10 (0.72,1.67)	153 (19)	0.89 (0.66,1.22)	272 (40)	1.36 (1.03,1.80)
PFHxS	234 (36)	0.95 (0.78,1.15)	153 (19)	1.01 (0.85,1.19)	272 (40)	1.09 (0.92,1.28)
High total:HDL cholesterol ratio (>4.5)						
PFOS (total)	250 (67)	0.94 (0.82,1.07)	153 (48)	1.05 (0.88,1.25)	277 (77)	1.02 (0.90,1.16)
PFOS (branched isomers)	250 (67)	1.02 (0.88,1.19)	150 (47)	1.14 (0.93,1.38)	255 (74)	1.08 (0.94,1.23)
PFOA	250 (67)	1.05 (0.80,1.37)	153 (48)	0.95 (0.76,1.19)	277 (77)	1.26 (1.00,1.60)
PFHxS	250 (67)	0.95 (0.85,1.06)	153 (48)	1.00 (0.88,1.15)	277 (77)	1.07 (0.96,1.19)
High triglycerides (>2 mmol/L)						
PFOS (total)	250 (86)	0.92 (0.80,1.05)	153 (65)	1.02 (0.88,1.18)	277 (93)	1.00 (0.88,1.13)
PFOS (branched isomers)	250 (86)	0.95 (0.83,1.10)	150 (63)	1.06 (0.89,1.26)	255 (91)	1.04 (0.90,1.20)
PFOA	250 (86)	1.08 (0.87,1.34)	153 (65)	1.08 (0.89,1.32)	277 (93)	1.14 (0.93,1.39)
PFHxS	250 (86)	0.93 (0.84,1.03)	153 (65)	1.04 (0.93,1.17)	277 (93)	1.02 (0.92,1.13)

	Katherine, NT		Oakey, Qld		Williamtown, NSW	
	N (cases) Exposed	Adjusted PR† (95% CI)	N (cases) Exposed	Adjusted PR† (95% CI)	N (cases) Exposed	Adjusted PR† (95% CI)
High serum creatinine^						
PFOS (total)	250 (9)	0.89 (0.65,1.20)	153 (12)	1.08 (0.63,1.88)	277 (7)	1.12 (0.76,1.65)
PFOS (branched isomers)	250 (9)	0.91 (0.64,1.28)	150 (11)	1.03 (0.46,2.33)	255 (5)	0.97 (0.54,1.72)
PFOA	250 (9)	0.94 (0.44,2.01)	153 (12)	1.02 (0.39,2.68)	277 (7)	1.74 (1.31,2.32)
PFHxS	250 (9)	0.85 (0.67,1.08)	153 (12)	1.10 (0.67,1.81)	277 (7)	0.99 (0.62,1.57)
High urate (uric acid)^						
PFOS (total)	250 (19)	1.19 (0.98,1.44)	153 (9)	1.34 (0.92,1.93)	277 (22)	1.23 (0.97,1.56)
PFOS (branched isomers)	250 (19)	1.20 (0.97,1.49)	150 (8)	0.93 (0.48,1.79)	255 (19)	1.36 (1.01,1.83)#
PFOA	250 (19)	1.72 (0.98,3.03)	153 (9)	1.12 (0.42,3.01)	277 (22)	1.99 (1.25,3.17)
PFHxS	250 (19)	1.01 (0.84,1.22)	153 (9)	1.05 (0.64,1.73)	277 (22)	1.06 (0.81,1.39)
Low eGFR (<60 mL/min/1.73 m2) CKD-EPI formula						
PFOS (total)	249 (7)	0.96 (0.64,1.43)	153 (9)	1.13 (0.61,2.08)	275 (9)	1.09 (0.77,1.53)
PFOS (branched isomers)	249 (7)	0.94 (0.61,1.47)	150 (9)	1.34 (0.53,3.35)	254 (7)	0.77 (0.53,1.12)
PFOA	249 (7)	0.79 (0.28,2.21)	153 (9)	1.42 (0.32,6.20)	275 (9)	1.25 (0.81,1.93)
PFHxS	249 (7)	0.93 (0.72,1.20)	153 (9)	1.15 (0.66,2.01)	275 (9)	0.97 (0.64,1.48)
High ALT^						
PFOS (total)	227 (12)	0.97 (0.63,1.48)	152 (10)	NC	274 (12)	1.46 (1.02,2.09)
PFOS (branched isomers)	227 (12)	0.95 (0.57,1.58)	149 (9)	NC	252 (12)	1.52 (0.98,2.36)
PFOA	227 (12)	0.89 (0.59,1.34)	152 (10)	NC	274 (12)	1.11 (0.67,1.85)
PFHxS	227 (12)	0.93 (0.68,1.28)	152 (10)	NC	274 (12)	1.20 (0.80,1.81)
High AST^						
PFOS (total)	249 (10)	0.92 (0.61,1.39)	153 (8)	1.39 (0.90,2.14)	276 (4)	NC
PFOS (branched isomers)	249 (10)	0.87 (0.51,1.49)	150 (6)	1.18 (0.59,2.37)	254 (4)	NC
PFOA	249 (10)	0.77 (0.49,1.22)	153 (8)	1.52 (0.88,2.62)	276 (4)	NC
PFHxS	249 (10)	0.95 (0.66,1.37)	153 (8)	1.19 (0.83,1.71)	276 (4)	NC
High GGT^						
PFOS (total)	250 (33)	0.95 (0.79,1.13)	153 (26)	1.08 (0.84,1.40)	277 (45)	1.14 (0.93,1.41)

	Katherine, NT		Oakey, Qld		Williamtown, NSW	
	N (cases) Exposed	Adjusted PR† (95% CI)	N (cases) Exposed	Adjusted PR† (95% CI)	N (cases) Exposed	Adjusted PR† (95% CI)
PFOS (branched isomers)	250 (33)	0.92 (0.73,1.15)	150 (25)	1.16 (0.82,1.63)	255 (43)	1.19 (0.93,1.51)
PFOA	250 (33)	1.06 (0.79,1.41)	153 (26)	1.29 (0.83,2.00)	277 (45)	1.35 (0.95,1.90)
PFHxS	250 (33)	0.95 (0.83,1.09)	153 (26)	0.98 (0.78,1.22)	277 (45)	1.12 (0.96,1.31)
High ALP^						
PFOS (total)	250 (11)	NC	153 (9)	1.02 (0.65,1.61)	276 (17)	1.20 (0.93,1.53)
PFOS (branched isomers)	250 (11)	NC	150 (9)	1.25 (0.73,2.12)	254 (15)	1.40 (1.05,1.86)
PFOA	250 (11)	NC	153 (9)	0.89 (0.63,1.25)	276 (17)	1.47 (0.78,2.77)
PFHxS	250 (11)	NC	153 (9)	1.10 (0.78,1.54)	276 (17)	0.98 (0.74,1.30)
Abnormal TSH^						
PFOS (total)	250 (8)	NC	153 (3)	0.55 (0.26,1.16)	276 (10)	1.23 (0.90,1.69)
PFOS (branched isomers)	250 (8)	NC	150 (3)	0.56 (0.27,1.17)	254 (7)	NC
PFOA	250 (8)	NC	153 (3)	4.49 (1.69,11.94)	276 (10)	0.84 (0.46,1.53)
PFHxS	250 (8)	NC	153 (3)	0.55 (0.39,0.78)	276 (10)	1.25 (0.93,1.69)

Effects are prevalence ratios per doubling in PFAS serum concentrations in exposed communities.

† Adjusted for age, sex, level of education and gross household annual income. Age was modelled using a restricted cubic spline with 3 knots.

^ Reference intervals vary by sex and age.

Estimated assuming an independence (rather than exchangeable) within-cluster correlation structure and cluster-robust standard errors.

N: sample size; PR: prevalence ratio; NC: convergence not achieved.

Table 10. Adjusted differences in mean lipid, liver, kidney and thyroid function biomarker concentrations per doubling in PFAS concentrations for residents and workers of PFAS Management Areas, 2016–2020.

	Katherine, NT		Oakey, Qld		Williamtown, NSW	
	N Exposed	Adjusted Difference† (95% CI)	N Exposed	Adjusted Difference† (95% CI)	N Exposed	Adjusted Difference† (95% CI)
Total Cholesterol (mmol/L)						
PFOS (total)	250	−0.01 (−0.10,0.09)	153	0.07 (−0.05,0.19)	277	0.11 (0.02,0.19)
PFOS (branched isomers)	250	−0.03 (−0.13,0.07)	150	−0.01 (−0.20,0.19)	255	0.10 (−0.00,0.20)
PFOA	250	0.13 (−0.01,0.26)	153	−0.02 (−0.27,0.24)	277	0.21 (0.07,0.35)
PFHxS	250	−0.02 (−0.10,0.05)	153	0.01 (−0.13,0.15)	277	0.10 (0.02,0.18)
HDL Cholesterol (mmol/L)						
PFOS (total)	250	0.02 (−0.01,0.05)	153	−0.00 (−0.04,0.04)	277	0.03 (−0.01,0.07)
PFOS (branched isomers)	250	0.00 (−0.03,0.04)	150	−0.02 (−0.06,0.02)	255	−0.00 (−0.04,0.03)
PFOA	250	0.03 (−0.02,0.08)	153	−0.00 (−0.05,0.05)	277	0.00 (−0.05,0.06)
PFHxS	250	0.02 (−0.00,0.04)	153	−0.00 (−0.03,0.03)	277	0.01 (−0.02,0.03)
LDL Cholesterol (mmol/L)						
PFOS (total)	234	0.01 (−0.08,0.09)	153	0.08 (−0.01,0.17)	272	0.06 (−0.02,0.13)
PFOS (branched isomers)	234	−0.02 (−0.12,0.08)	150	0.05 (−0.06,0.16)	250	0.05 (−0.04,0.15)
PFOA	234	0.12 (−0.01,0.25)	153	0.07 (−0.06,0.20)	272	0.14 (0.02,0.26)
PFHxS	234	−0.03 (−0.11,0.04)	153	0.02 (−0.05,0.10)	272	0.08 (0.01,0.14)
Total:HDL Cholesterol ratio						
PFOS (total)	250	−0.05 (−0.16,0.05)	153	0.06 (−0.08,0.20)	277	0.01 (−0.09,0.11)
PFOS (branched isomers)	250	−0.01 (−0.13,0.11)	150	0.05 (−0.15,0.25)	255	0.10 (−0.02,0.21)
PFOA	250	−0.00 (−0.18,0.17)	153	−0.03 (−0.31,0.26)	277	0.21 (0.07,0.36)
PFHxS	250	−0.06 (−0.14,0.02)	153	0.02 (−0.14,0.17)	277	0.07 (−0.02,0.15)
Triglycerides (mmol/L)						
PFOS (total)	250	−0.08 (−0.18,0.02)	153	0.05 (−0.09,0.19)	277	0.01 (−0.09,0.12)
PFOS (branched isomers)	250	−0.06 (−0.17,0.06)	150	0.01 (−0.13,0.15)	255	0.05 (−0.07,0.17)
PFOA	250	0.01 (−0.13,0.15)	153	−0.01 (−0.17,0.16)	277	0.13 (−0.01,0.27)
PFHxS	250	−0.06 (−0.13,0.01)	153	0.05 (−0.08,0.18)	277	0.03 (−0.05,0.11)

	Katherine, NT		Oakey, Qld		Williamtown, NSW	
	N Exposed	Adjusted Difference† (95% CI)	N Exposed	Adjusted Difference† (95% CI)	N Exposed	Adjusted Difference† (95% CI)
Serum creatinine (umol/L)						
PFOS (total)	250	0.38 (−1.05,1.82)	153	0.66 (−1.54,2.86)	277	0.16 (−0.87,1.19)
PFOS (branched isomers)	250	0.51 (−0.93,1.95)	150	−0.36 (−3.80,3.08)	255	−0.15 (−1.47,1.18)
PFOA	250	−0.86 (−4.60,2.87)	153	0.24 (−3.93,4.41)	277	−0.37 (−2.01,1.26)
PFHxS	250	−0.73 (−1.67,0.22)	153	−0.01 (−2.42,2.41)	277	−0.27 (−1.32,0.78)
Urate (uric acid) (mmol/L)						
PFOS (total)	250	−0.00 (−0.01,0.01)	153	0.00 (−0.01,0.01)	277	0.00 (−0.00,0.01)
PFOS (branched isomers)	250	0.00 (−0.01,0.01)	150	−0.00 (−0.02,0.01)	255	0.01 (0.00,0.02)
PFOA	250	0.01 (0.00,0.02)	153	0.01 (−0.01,0.02)	277	0.02 (0.01,0.03)
PFHxS	250	−0.00 (−0.01,0.00)	153	−0.00 (−0.01,0.01)	277	0.00 (−0.00,0.01)
eGFR (mL/min/1.73 m2) CKD-EPI formula						
PFOS (total)	249	−0.28 (−1.52,0.95)	153	−1.07 (−2.92,0.77)	275	−0.09 (−1.06,0.88)
PFOS (branched isomers)	249	−0.53 (−1.88,0.82)	150	−0.39 (−3.00,2.22)	254	0.06 (−1.15,1.27)
PFOA	249	0.02 (−2.69,2.72)	153	−0.75 (−3.81,2.32)	275	0.39 (−1.23,2.01)
PFHxS	249	0.66 (−0.24,1.56)	153	−0.48 (−2.33,1.36)	275	0.24 (−0.70,1.19)
ALT (U/L)						
PFOS (total)	227	−0.77 (−1.75,0.22)	152	0.43 (−0.87,1.74)	274	0.31 (−0.54,1.15)
PFOS (branched isomers)	227	−0.76 (−1.91,0.40)	149	0.58 (−1.03,2.19)	252	0.96 (−0.09,2.01)
PFOA	227	−0.38 (−1.56,0.81)	152	0.54 (−0.82,1.90)	274	0.51 (−0.65,1.68)
PFHxS	227	−0.73 (−1.51,0.05)	152	0.11 (−0.85,1.06)	274	0.30 (−0.42,1.02)
AST (U/L)						
PFOS (total)	249	−0.69 (−1.66,0.28)	153	0.75 (−0.56,2.06)	276	0.13 (−0.40,0.66)
PFOS (branched isomers)	249	−0.59 (−1.75,0.57)	150	0.33 (−0.82,1.48)	254	0.32 (−0.34,0.98)
PFOA	249	−0.16 (−1.22,0.89)	153	1.63 (0.60,2.65)	276	0.74 (−0.14,1.63)
PFHxS	249	−0.64 (−1.37,0.10)	153	0.51 (−0.43,1.46)	276	−0.14 (−0.65,0.3)
GGT (U/L)						
PFOS (total)	250	1.63 (−1.98,5.25)	153	0.55 (−2.09,3.19)	277	0.83 (−1.57,3.22)

	Katherine, NT		Oakey, Qld		Williamtown, NSW	
	N Exposed	Adjusted Difference† (95% CI)	N Exposed	Adjusted Difference† (95% CI)	N Exposed	Adjusted Difference† (95% CI)
PFOS (branched isomers)	250	1.22 (−2.84,5.27)	150	0.87 (−2.47,4.21)	255	1.07 (−1.51,3.66)
PFOA	250	1.19 (−2.30,4.69)	153	0.83 (−1.66,3.31)	277	1.42 (−1.33,4.17)
PFHxS	250	1.52 (−0.96,4.00)	153	0.25 (−1.79,2.29)	277	0.38 (−1.40,2.16)
ALP (U/L)						
PFOS (total)	250	0.15 (−1.99,2.29)	153	−0.91 (−2.90,1.08)	276	−1.05 (−2.80,0.70)
PFOS (branched isomers)	250	−0.08 (−2.46,2.30)	150	0.81 (−1.57,3.20)	254	0.88 (−1.20,2.96)
PFOA	250	1.77 (−0.94,4.48)	153	−0.87 (−3.48,1.74)	276	1.24 (−1.99,4.47)
PFHxS	250	−0.05 (−1.87,1.76)	153	0.13 (−1.56,1.82)	276	−0.89 (−2.56,0.79)
Serum albumin (g/L)						
PFOS (total)	250	−0.06 (−0.33,0.21)	153	0.42 (0.10,0.73)	277	0.08 (−0.14,0.31)
PFOS (branched isomers)	250	−0.05 (−0.34,0.25)	150	0.38 (−0.01,0.77)	255	0.12 (−0.16,0.40)
PFOA	250	0.32 (−0.17,0.81)	153	0.48 (0.03,0.93)	277	0.27 (−0.09,0.64)
PFHxS	250	−0.13 (−0.35,0.09)	153	0.19 (−0.06,0.43)	277	0.06 (−0.15,0.27)
Total protein (g/L)						
PFOS (total)	250	−0.05 (−0.43,0.34)	153	0.64 (0.10,1.17)	277	−0.07 (−0.45,0.30)
PFOS (branched isomers)	250	−0.00 (−0.44,0.44)	150	0.44 (−0.16,1.04)	255	0.08 (−0.39,0.54)
PFOA	250	0.48 (−0.11,1.07)	153	0.47 (−0.19,1.13)	277	0.40 (−0.12,0.92)
PFHxS	250	−0.19 (−0.52,0.14)	153	0.38 (−0.03,0.78)	277	0.04 (−0.31,0.39)
TSH (mIU/L)						
PFOS (total)	250	−0.01 (−0.07,0.05)	153	−0.02 (−0.11,0.07)	276	0.01 (−0.05,0.06)
PFOS (branched isomers)	250	−0.01 (−0.08,0.07)	150	0.02 (−0.08,0.11)	254	−0.00 (−0.08,0.07)
PFOA	250	0.09 (−0.02,0.21)	153	0.12 (−0.01,0.26)	276	0.04 (−0.06,0.14)
PFHxS	250	−0.00 (−0.05,0.05)	153	−0.01 (−0.08,0.06)	276	−0.02 (−0.08,0.03)
Free T3 (pmol/L)						
PFOS (total)	250	−0.01 (−0.05,0.02)	153	0.01 (−0.05,0.08)	276	−0.01 (−0.05,0.03)
PFOS (branched isomers)	250	0.01 (−0.04,0.06)	150	0.01 (−0.07,0.09)	254	0.03 (−0.02,0.09)
PFOA	250	0.01 (−0.05,0.07)	153	−0.02 (−0.10,0.06)	276	−0.01 (−0.08,0.07)

	Katherine, NT		Oakey, Qld		Williamtown, NSW	
	N Exposed	Adjusted Difference† (95% CI)	N Exposed	Adjusted Difference† (95% CI)	N Exposed	Adjusted Difference† (95% CI)
PFHxS	250	−0.00 (−0.03,0.03)	153	−0.01 (−0.07,0.05)	276	−0.01 (−0.04,0.03)
Free T4 (pmol/L)						
PFOS (total)	249	−0.00 (−0.10,0.10)	153	0.08 (−0.05,0.21)	276	−0.01 (−0.13,0.12)
PFOS (branched isomers)	249	0.04 (−0.08,0.16)	150	0.11 (−0.03,0.25)	254	0.04 (−0.12,0.19)
PFOA	249	0.04 (−0.13,0.22)	153	0.08 (−0.08,0.24)	276	−0.02 (−0.23,0.19)
PFHxS	249	−0.03 (−0.11,0.06)	153	0.06 (−0.04,0.17)	276	0.08 (−0.03,0.19)

Effects are differences in mean biomarker concentrations per doubling in PFAS serum concentrations in exposed communities.

† Adjusted for age, sex, level of education and gross household annual income. Age was modelled using a restricted cubic spline with 3 knots.

N: sample size; NC: convergence not achieved.

Discussion

Contamination of the local environment surrounding the Australian Defence Force bases in Katherine, Oakey and Williamtown led to substantial concern about potential PFAS among community members and associated health effects. Understanding PFAS exposure in these communities is vital to addressing these concerns and informing ongoing responses. This study summarises blood serum PFAS concentrations in people who have lived or worked in the Katherine, Oakey and Williamtown PFAS Management Areas and compares blood serum PFAS concentrations to people who live in similar communities not affected by environmental PFAS contamination: Alice Springs, Dalby, and Kiama and Shellharbour. We discuss risk factors associated with elevated blood serum PFAS concentrations among people who have lived in Katherine, Oakey and Williamtown, examining exposure in people who consumed bore water and certain locally grown produce, were directly exposed to firefighting foams in their workplace or community, or had lived in the PFAS Management Areas for a long period of time. To assess the human health effects associated with PFAS exposure in these communities, we investigated the relationship between blood serum PFAS concentrations and blood serum biochemical markers of kidney, liver and thyroid function and lipid concentrations. Throughout this discussion, we consider the main findings of each component of the Blood Serum Study in the context of previous research conducted on PFAS exposure and outline the strengths and limitations associated with our findings.

Serum PFAS concentrations in Katherine, Oakey and Williamtown

A summary of the main findings for blood serum PFAS concentrations in exposed and comparison communities is included in Box 4.

Interpretation of the findings in the context of previous research

Epidemiological studies show increased exposure to long-chain perfluoroalkyl substances in communities impacted by environmental PFAS contamination.[16,17,47-49,77] Consistent with the literature, we found high detection rates of PFOS, PFHxS and PFOA in blood serum of residents and workers of the PFAS Management Areas who participated in the Blood Serum Study, which reflects the stability of these chemicals in the environment and the long elimination half-life in the human body.[1,7,23,25] We observed higher geometric means of blood serum PFOS and PFHxS concentrations in Katherine, Oakey and Williamtown compared to other similar communities in Australia not affected by environmental PFAS contamination: Alice Springs, Dalby, and Kiama and Shellharbour. Geometric means of serum PFOA concentrations in Katherine, Oakey and Williamtown participants were equivalent to the background exposure levels we measured in participants from the comparison communities, which is indicative of general exposure to PFOA through household products, rather than environmental contamination. The small differences in geometric means of PFOA concentrations across the PFAS Management Areas is likely attributable to differences in the sampling periods of exposed and comparison communities, which we discuss later. Evidence of increased PFOS and PFHxS exposure in Katherine, Oakey and Williamtown reflects the composition of AFFF historically used on the RAAF Bases at Tindal and Williamtown and the Oakey Army Aviation Centre.[54] The concentration profile of serum PFAS in residents and workers is consistent with the environmental sampling of the PFAS Management Areas, which showed PFOS and PFHxS as the predominant PFAS measured in groundwater, surface water and soil.[51,62]

Box 4. Summary of main findings for serum PFAS concentrations in Katherine, Oakey and Williamtown.

Evidence of higher serum PFOS and PFHxS concentrations in residents and workers of the Katherine, Oakey and Williamtown PFAS Management Areas.

Among participants of the Blood Serum Study, geometric means of blood serum PFOS and PFHxS concentrations were higher for residents and workers of Katherine, Oakey and Williamtown, compared to residents of Alice Springs, Dalby, and Kiama and Shellharbour, respectively. Geometric means of blood serum PFAS concentrations of participants from the exposed communities were approximately two times as high as participants from the comparison communities for PFOS and two to six times as high as participants from the comparison communities for PFHxS. In contrast, serum PFOA concentrations in participants from Katherine, Oakey and Williamtown reflect the background exposure levels observed in participants from the comparison communities.

Blood serum PFOS and PFHxS concentrations were associated with Zones of higher contamination of groundwater and soil in the Oakey and Williamtown PFAS Management Areas.

Geometric means of blood serum PFOS and PFHxS concentrations were higher among current residents of the Primary Management Area Zone in Oakey and Williamtown, compared to residents of the Broader Management Area Zone. In Oakey, geometric means of blood serum PFAS concentrations of participants from the Primary Management Zone were five times as high for PFOS and six times as high for PFHxS, compared to participants from the Broader Zone. In Williamtown, geometric means of blood serum PFOS and PFHxS concentrations of participants from the Primary Zone were twice as high, compared to participants from the Broader Zone.

Half of residents and workers of the Katherine, Oakey and Williamtown PFAS Management Areas had an elevated serum PFHxS concentration and a third had an elevated serum PFOS concentration.

Across Katherine, Oakey and Williamtown, 48% to 55% of adult participants of the Blood Serum Study had an elevated serum PFHxS concentration, above the 95th percentile serum PFHxS concentration of participants from the comparison communities. In total, 29% to 42% of participants across Katherine, Oakey and Williamtown had an elevated serum PFOS concentration. In contrast, 6% to 14% of had an elevated serum PFOA concentration.

Serum PFAS concentrations of Blood Serum Study participants from Katherine, Oakey and Williamtown are comparable to those reported for US communities affected by environmental contamination from AFFF use on military bases.[47-49] A study of people who had ever lived or worked in New Hampshire, US, and consumed contaminated drinking water, showed geometric mean serum PFOS and PFHxS concentrations of 8.6 ng/mL and 4.1 ng/mL respectively, equivalent to the serum PFOS and PFHxS concentrations observed in participants who had ever lived or worked in Katherine, Oakey and Williamtown.[48] Further, a recent study of current residents in Pennsylvania, US, is consistent with the exposure of current residents in Oakey, reporting geometric mean serum PFOS and PFHxS concentrations of 10.2 ng/mL and 6.6 ng/mL, respectively.[47] Serum PFAS concentrations were marginally higher in participants of the PFAS-AWARE Study in El Paso County in Texas, US, and show a different exposure profile with serum PFHxS at higher concentrations than serum PFOS: the median PFOS concentration was 9.7 ng/mL whereas the median PFHxS concentration was 14.8 ng/mL.[49] Differences in average PFOS and PFHxS compared to our study may be explained by the fact that participant recruitment in the PFAS-AWARE study was restricted to current residents who had lived in the community for at least two years, rather than people who had ever lived or worked in the affected areas.[49] Although we see similarities in the serum PFAS concentrations in our study and these US communities, these findings may not reflect exposure in all populations affected by environmental PFAS contamination arising from AFFF use. For example, serum PFAS concentrations observed in Katherine, Oakey and Williamtown are far below exposure concentration measured in a Swedish population.[77] Among residents of Ronneby, Sweden, the geometric mean serum PFHxS concentration was 114 ng/mL following exposure to

water contaminated with AFFF, which was 135 times as high as serum PFAS concentration of people from a nearby comparison community.[77] Further, the geometric mean serum PFOS concentration was 135 ng/mL, representing exposure 20 to 28 times as high as we observed in Katherine, Oakey and Williamtown.[77] However, the concentration profile of serum PFAS in Ronneby residents is consistent with our findings; there were smaller differences in average PFOA concentrations in exposed and comparison communities compared to estimates for PFOS and PFHxS.[77] The results of the US and Swedish studies show background exposure levels of serum PFOA concentrations in communities impacted by environmental contamination from AFFF use, reflecting our findings for Katherine, Oakey and Williamtown.

Notably, lower serum PFAS concentrations among participants from Katherine, Oakey and Williamtown, compared to residents from Ronneby, may be explained by the measurements of PFAS contamination in local water sources. Environmental sampling of the Ronneby municipal water supply in 2013 found combined PFOS+PFHxS concentrations of 9.7 micrograms per litre (µg/L).[15] Baseline measurements of groundwater in Katherine show PFOS+PFHxS concentrations of 0.1–1.2 µg/L in residential bore water sources in the township and PFOS+PFHxS concentrations of 0.1–4.2 µg/L in sources on rural properties located closed to the RAAF Base Tindal.[57] In Oakey, the median PFOS concentration was considerably lower (0.1 µg/L) in residential bore water sources, and in Williamtown only 15% (32/211) of private bore water samples had detectable PFAS concentrations.[78,79] Environmental sampling in the US communities further highlight the association of PFAS detected in the environment and human serum. In New Hampshire, the drinking water supply from groundwater wells contained PFOS and PFHxS concentrations of 2.5 µg/L and 0.8 µg/L respectively, and in Pennsylvania, PFOS concentrations measured in drinking water ranged from 0.1 µg/L to 1.1 µg/L, showing similarities to measurements in Katherine, Oakey and Williamtown.[47,48] However, the maximum PFOS concentrations detected in residential bore water samples were 39.2 µg/L and 77.1 µg/L in Oakey and Williamtown, respectively, indicating that some residents may have been exposed to water with higher concentration of PFAS than other residents of the PFAS Management Areas, among those who had a private bore water supply.[78,79] Although there are key differences in the nature of the contamination, an Italian study of PFOA exposure reported that the concentrations of PFAS in the water supply were the strongest determinant of concentrations observed in blood serum.[17] Higher serum PFOS and PFHxS concentrations in participants who were residents of the Primary Management Zones in Oakey and Williamtown compared to the Broader Management Zones, also suggest an association with higher serum PFAS concentrations in residents who live in areas that have higher levels of contamination in the environment.[50,52]

Irrespective of levels of PFAS measured in the local environment, age and gender are key determinants of serum PFAS concentrations.[16,47-49,80-82] Our findings show that serum PFOS, PFHxS and PFOA concentrations are lower in females than males; a conclusion consistent with the epidemiological literature. Females eliminate PFAS at a higher rate than males, excreting PFAS through menstrual loss and during pregnancy and breastfeeding.[83,84] However, these elimination pathways for females also represent exposure pathways for infants. A study in Norway showed higher PFOS and PFOA concentrations in newborns than mothers at the time of birth, associated with transplacental transfer of PFAS during pregnancy.[85,86] Blood serum PFAS concentrations in infants may increase by 3–6% per month of breastfeeding; however, increases may be as high as 30% per month of exclusive breastfeeding.[84,86,87] Increases in potential exposure to PFAS (in the environment or in household products) during hand-to-mouth behaviours in young children may explain non-linear associations of serum PFAS concentrations and age observed in epidemiological literature.[88] Low recruitment numbers limited our conclusions on exposure in infants and children from Katherine, Oakey and Williamtown. However, our findings support conclusions that PFAS exposure is higher in older adults than younger adults, reflecting cumulative exposure over time.[47-49,82] Importantly, not all epidemiological studies find non-linear

association of serum PFAS concentrations and age, which could be explained by the different half-lives of some PFAS and other determinants of PFAS exposure.[16,89,90] Blood serum PFAS concentrations are the result of past cumulative exposures, including dietary intake and household items, and other factors which influence elimination, such as blood donation and kidney function.[1,14,17,91] However, in communities affected by environmental contamination, it is important to consider specific factors that could influence cumulative PFAS exposure, such as water intake, length of time spent in the affected area and occupation.[1,14]

Risk factors for elevated serum PFAS concentrations

A summary of the main findings for the determinants of elevated blood serum PFAS concentrations in exposed residents is included in Box 5.

Box 5. Summary of main findings for risk factors for elevated serum PFAS concentrations.

Most residents of the Katherine, Oakey and Williamtown PFAS Management Areas reduced their use of bore water and consumption of local produce after they were made aware of the environmental contamination.

Adult residents of the PFAS Management Areas who participated in the Blood Serum Study and Cross-sectional Survey reported changes to their bore water use and local produce consumption to reduce their potential exposure to PFAS after they learned of the contamination. In total, 78% of residents across Katherine, Oakey and Williamtown ceased bore water use, or used bore water for fewer household activities, after they were made aware of the contamination. Following notification of the contamination, 35% of residents who were living in the PFAS Management Areas changed their consumption of locally grown produce.

Consumption of bore water and certain locally grown foods, firefighting foam exposure in the workplace, and years of residence in a PFAS Management Area were risk factors for elevated serum PFOS and PFHxS concentrations.

Among adult residents of the PFAS Management Areas, we observed a higher odds of elevated serum PFOS and PFHxS concentrations associated with frequent (at least weekly) ingestion of bore water in Oakey, frequent consumption of locally grown produce defined as high-risk and occupational firefighting foam (AFFF) exposure in Williamtown, and length of residence in Katherine and Williamtown.

Interpretation of the findings in the context of previous research

Environmental assessments identified household use of bore water and consumption of some types of local produce (including eggs, fruit and vegetables, livestock and fish) as the primary PFAS exposure pathways for residents of Katherine, Oakey and Williamtown.[50-52] Our findings support the conclusions of these risk assessments, identifying associations of bore water ingestion and local produce consumption with elevated serum PFOS and PFHxS concentrations. In Oakey, we found a strong association between bore water ingestion and elevated serum PFAS concentrations in residents; we are less certain about the association in Katherine and Williamtown. Water sources are a major exposure pathway related to environmental contamination; however, epidemiological studies show inconsistent results for the association of water consumption and serum PFAS concentrations.[1,47,48,80,92] Uncertain or null-findings may be explained by the use of self-reported data to assess water consumption in community members.[48] However, variation in the association observed in Katherine, Oakey and Williamtown could also relate to the levels of PFAS measured in bore water sources. In Oakey, 45% (54/119) of residential bore water supplies had PFOS concentrations above the Australian recommendations for safe drinking water, whereas in Williamtown 85% (179/211) of samples collected from residential bore water sources had undetectable PFAS concentrations.[66,79,93] Notably, in Katherine the town water supply is extracted from the Katherine River and groundwater, which represents another potential

exposure pathway for residents prior to implementation of the PFAS water treatment system in October 2017.[51] Uncertainty in the association of bore water ingestion and elevated PFAS levels in Katherine may reflect historic exposure to PFAS through the local town water, in addition to private bore water supplies.

Dietary intake, particularly fish consumption, is associated with higher concentrations of PFAS exposure in the general population.[1,14] However, consumption of produce grown in areas affected by environmental contamination is not typically assessed in relation to serum PFAS concentrations across studies of impacted communities.[1] Our findings show a strong association between consumption of local produce impacted by PFAS (including eggs, fruit and vegetables, and livestock) and elevated serum PFOS and PFHxS concentrations in Williamtown, which highlights the importance of assessing this exposure pathway. In Katherine and Williamtown, duration of residence was also strongly associated with elevated PFAS levels, which is a common finding across epidemiological studies of communities affected by environmental contamination.[47,48,80,81] In the absence of strong associations between water consumption or dietary intake and serum PFAS concentrations, as in Katherine, associations of length of time spent in a contaminated area may suggest that other exposure pathways are affecting serum PFAS concentrations. However, studies also highlight the need to consider occupational exposures to PFAS, particularly where the environmental contamination stems from a specific type of work, such as a PFAS manufacturing facility or firefighting.[1,49,73,94] In our study, we observed some associations between occupational AFFF use and elevated serum PFAS concentrations; however, the results were largely inconclusive. Aviation firefighters exposed to AFFF have serum PFOS and PFHxS concentrations above the levels observed in our study, likely due to the infrequent use of AFFF in residents of Katherine, Oakey and Williamtown who reported occupational exposure to AFFF.[73] Use of AFFF was predominantly restricted to annual firefighting training or general firefighting activities less than weekly. Further, we observed no consistent observations of household or community-based exposure to AFFF in our study, which reflects infrequent and non-ongoing exposure in this setting. Non-occupational exposure to AFFF in communities affected by environmental contamination was a specific concern raised in focus group discussions conducted in an earlier in component of the PFAS Health Study.[64]

The cross-sectional nature of this study limits our conclusions on the causal relationship of consumption patterns and elevated serum PFAS concentrations. Nonetheless, our findings support the need for ongoing measures to minimise potential sources of PFAS exposure in Katherine, Oakey and Williamtown. This study links bore water ingestion and local produce consumption with a higher likelihood of elevated serum PFAS concentrations, supporting limits to these activities. However, our findings also show that many residents changed the use of bore water in their household and consumption of local produce after they became aware of the contamination. This suggests that there are potential changes to the risk of PFAS exposure in recent years that were not assessed in our study. Follow-up epidemiological research may help us to understand the impact of the public health interventions in Katherine, Oakey and Williamtown. Ongoing longitudinal research by the Queensland Alliance for Environmental Health Sciences at the University of Queensland (funded by the Australian Government National Health and Medical Research Council) is investigating the rates and determinants of serum PFAS elimination in residents and workers of Katherine, Oakey and Williamtown who had elevated serum PFAS concentrations in the Blood Serum Study.

Biochemical markers of health

A summary of the main findings for the associations between blood serum PFAS concentrations and biochemical markers of health is included in Box 6. We describe the associations between serum PFAS concentrations and biochemical markers in the context of self-reported health outcomes in the Cross-sectional Survey Report.[65] In this discussion, we briefly outline the main

findings of our study in the context of previous research. Notably, the cross-sectional associations observed in our study cannot be used to determine causation. Explanations of the biological mechanisms associated with these health outcomes are also detailed in the Cross-sectional Survey Report.[65]

Box 6. Summary of main findings for biochemical markers of health.

Higher serum PFAS concentrations were associated with elevated cholesterol concentrations in participants from the Williamtown PFAS Management Area.

In Williamtown, we observed higher prevalence of elevated (higher than the upper reference limit) total cholesterol per doubling in serum PFOS, PFHxS and PFOA concentrations and higher mean total cholesterol concentrations, LDL concentrations and the total cholesterol to HDL ratio. However, estimated differences in mean lipid biomarker concentrations were small (close to zero). The evidence was substantially weaker for an association between serum PFAS and lipid concentrations in participants from the Katherine and Oakey PFAS Management Areas.

Higher serum PFAS concentrations were associated with elevated uric acid concentrations in participants from the Katherine and Williamtown PFAS Management Areas.

In Katherine and Williamtown, we observed higher prevalence of elevated urate (uric acid) per doubling in serum PFOS, PFHxS and PFOA concentrations. The effects were strongest for serum PFOA concentrations. However, differences in mean serum urate and other biochemical markers of kidney function per doubling in PFAS serum concentrations were small. The prevalence of adverse kidney function biomarker concentrations in Oakey were imprecisely estimated and inconclusive.

Higher serum PFAS concentrations were not clearly associated with elevated concentrations of liver function biomarkers in participants from the Katherine, Oakey and Williamtown PFAS Management Areas.

In Williamtown, we observed higher prevalence of elevated ALT, GGT and ALP per doubling in PFAS serum concentrations; however, our findings were based on few cases with mild elevations of the concentrations of these liver function biomarkers and could be due to missing data. Further, the findings in Williamtown were not supported by the analyses in Katherine and Oakey. Differences in mean ALT, AST, ALP, GGT, total protein and serum albumin per doubling in PFAS serum concentrations were small.

Interpretation of the findings in the context of previous research

Epidemiological investigations of PFAS exposure and biomarkers of disease risk indicate a range of potential metabolic effects, including changes in kidney, liver and thyroid function and blood lipid concentrations.[14,27,28,68] Our findings of higher prevalence of elevated total cholesterol with increases in serum PFAS concentrations are consistent with current epidemiological literature, which identifies hypercholesterolaemia as a health outcome associated with PFAS exposure.[14,38,68] However, our study shows only small differences in average lipid biomarker concentrations, which supports the conclusion that changes in cholesterol associated with PFAS exposure are unlikely to be clinically significant. Notably, residents of Ronneby, Sweden, had blood serum total cholesterol levels 7% higher and LDL levels 9% higher than residents of a nearby comparison community.[15] Although our study of lipid levels was limited to adults from Katherine, Oakey and Williamtown, research shows a similar effect in children and pregnant women.[28,29,95]

Studies show associations of PFAS exposure with reductions in kidney function.[27,33] However, as the kidneys are a key site of PFAS elimination and reabsorption, cross-sectional studies cannot rule out reverse causation; pre-existing decreased kidney function may result in lower rates of PFAS excretion and, consequently, higher serum PFAS concentrations.[96] Our study shows higher prevalence of elevated urate (uric acid) with increases in serum PFAS concentrations. Although uric acid concentration is an indicator of kidney function, increases in urate are also associated with some cancers and dietary intake of purines, found in high concentrations in alcohol, seafood and some livestock.[97-99] Similar to the findings for cholesterol, our study found a small difference

in average serum urate, serum creatinine and eGFR per doubling in PFAS concentration, which indicates PFAS exposure is not associated with marked changes in kidney function in residents and workers of Katherine, Oakey and Williamtown. In further support of these conclusions, associations of serum PFOS and PFHxS concentrations and self-reported kidney disease in the Cross-sectional Survey were in the opposite direction to what we would expect to see if increasing exposure to PFAS adversely affects kidney function.[65]

Associations of serum PFAS concentrations and biochemical markers of liver and thyroid function are largely inconsistent across epidemiological literature.[68] In the PFAS Health Study Systematic Review, we concluded that there was inadequate evidence that PFAS exposure is associated with adverse effects on the liver and thyroid.[63] Recent studies of highly exposed populations show potential associations between PFAS and changes in thyroid function.[100-102] However, the increased use of hypothyroidism medication in residents of Ronneby, Sweden, compared to a comparison community was considered likely to be a finding due to chance.[100] Our findings largely support no association of serum PFAS concentrations and biochemical markers of abnormal thyroid function (TSH, free T3 and free T4) across Katherine, Oakey and Williamtown. Although we observed higher prevalence of abnormal TSH concentrations in Oakey, estimates were based on a very small number of cases and could also reflect a chance finding.

Our study suggested higher prevalence of elevated ALT, GGT and ALP (markers of impaired liver function) in Williamtown; however, results were not consistent across the PFAS Management Areas. Almost all elevated liver function biomarker concentrations were mildly elevated, so our observations in Williamtown may be due to outcome misclassification. In the absence of clinical symptoms, biomarker values outside of reference intervals are not necessarily indicative of disease. Other factors unrelated to PFAS exposure, such as alcohol consumption, can acutely affect concentrations of liver function biomarkers.[103] While research shows unclear evidence of the association of serum PFAS concentrations and biomarkers of liver function, toxicological studies of PFAS exposure show potential biological pathways leading to liver damage, indicating the importance of future research in this area.[68]

Study strengths and limitations

A strength of the Blood Serum Study was the integration of data collected across several components of the PFAS Health Study, including the Systematic Review, Focus Groups Study and Cross-sectional Survey, to gain insight into PFAS exposure and the associated health effects in Katherine, Oakey and Williamtown.[63-65] Further, the Study included individual blood serum PFAS measurements for participants from exposed and comparison communities, which were selected within the same state or territory and similar in sociodemographic characteristics. Although there are strengths to our study design, it is important to consider the limitations of the Blood Serum Study in context. A key limitation was the time differences in blood sample collection in participants from the exposed and comparison communities. Additional limitations are explained below, many of which related to the cross-sectional design of our study, which represents data collected at one point in time.

Selection bias

Our study population is not representative of the populations of Katherine, Oakey and Williamtown, or Alice Springs, Dalby, and Kiama and Shellharbour. Approximately 7% of current residents of the exposed communities participated in the Blood Serum Study. Community members chose whether or not to participate in the Blood Serum Study and, therefore, our study population was 'self-selected', not randomly sampled. A smaller proportion of current residents chose to participate in the Cross-sectional Survey and consented to biochemical marker testing of their blood sample. Self-selection may bias our effect estimates. For example, participants of the Blood Serum Study

may have been more concerned about their exposure to PFAS due to their use of bore water, consumption of locally grown produce, or use of firefighting foams in their occupation than non-participants. Therefore, our estimates of serum PFAS concentrations in residents and workers of Katherine, Oakey and Williamtown may be an overestimation of exposure to PFAS across the communities. This means that we should be cautious in generalising the findings of the Blood Serum Study to the general populations of Katherine, Oakey and Williamtown, and to people who have ever lived or worked in these communities.

Although we randomly sampled residents of the populations of Alice Springs, Dalby, and Kiama and Shellharbour through the Medicare Enrolment File, only 3% of people invited to participate in the Blood Serum Study. Therefore, serum PFAS concentrations measured in participants from the comparison communities are also not representative of the general populations of these communities. However, it is likely that serum PFAS concentrations in the comparison communities are representative of background levels observed in the general population of Australia, as the results are consistent with blood sampling results for other Australian communities.[2,104]

The findings of our study are further limited by the low participation rates in some of the exposed and comparison communities. To recruit participants, we promoted the study through several media platforms and other avenues specific to each community and provided inclusive options for participation, including the option to complete the survey online or in a paper format and via telephone with our study team if required. The Australian Government also extended the VBTP to allow for greater recruitment into the Blood Serum Study. We engaged with potential participants online, via telephone and in person to increase recruitment; however, we acknowledge that the issue of PFAS contamination is highly contentious for some members of the Katherine, Oakey and Williamtown communities. Moreover, recruitment of people who previously lived or worked in these exposed communities, as well as people from the comparison communities who had limited knowledge of PFAS contamination, relied heavily on direct communication with potential participants, which was mostly limited to letters posted to residential addresses. Consequently, we had high levels of recruitment losses related to changes in addresses over the study period, particularly for people who previously lived and worked in the exposed communities.

Measurement error

Serum PFAS measurement

Differences in the serum collection period of exposed and comparison communities of one to three years is an important limitation to consider in our comparisons of PFAS exposure. In Australia, there have been gradual declines in PFOS, PFHxS and PFOA in pooled blood serum samples since 2002.[2,89,104] Therefore, our estimates of the differences between serum PFAS concentrations of participants from the exposed and comparison communities may be overestimated. In particular, the small differences in geometric means of serum PFOA concentrations for the exposed and comparison communities may be attributable to the differences in the data collection periods. Studies of pooled blood samples from the general population of Australia show decreases in median PFOA concentrations from 2.21 ng/mL in 2014–15 to 2.11 ng/mL in 2016–17, equivalent to a 4.5% decrease over two years.[2] Decreases in serum PFOA concentrations in the general population of Australia were larger in previous years.[104] The time delays for sampling in the comparison communities were unavoidable, as the COVID-19 pandemic affected our ability to engage participants and collect blood specimens. However, our estimates of the differences between serum PFOS and PFHxS concentrations of the exposed and comparison communities were considerably higher than for serum PFOA concentrations and are unlikely to be explained by the different sampling periods alone.

Variation in serum PFAS testing procedures may have also occurred over the study, with PFAS testing conducted over four years. We controlled for variation in testing by having samples from

the exposed and comparison communities tested at a central laboratory under the same testing protocols. To minimise laboratory testing variation, Sonic Healthcare analysed all blood serum samples in duplicate with procedural blanks and a standardised reference material to internally control for contamination and accuracy. Testing of biochemical markers were conducted for samples from the exposed and comparison communities over the same time period using the same machines in the central laboratory to minimise potential biases from these sources.

Exposure and confounder misclassification

Our analysis of the risk factors associated with elevated PFAS levels in residents of Katherine, Oakey and Williamtown provides some explanations for higher serum PFAS concentrations in some participants. However, this analysis relied on self-reported data collected in the Cross-sectional Survey, which were potentially affected by reporting biases. Participants from the exposed communities had access to their PFAS test results before we conducted the survey. It is possible that people with elevated blood serum levels of PFAS in exposed communities had better recall of exposure to environmental factors, such as use of bore water or consumption of local produce, than people with lower serum PFAS concentrations. It is difficult to assess the influence of reporting (or recall) bias on our estimates. Further, we were limited in the number of questions we asked study participants in the Cross-sectional Survey, which meant that we did not capture some important risk factors related to exposure, including other sources of PFAS in the household.[1] Further explanations of the limitations associated with the design of the survey, including biases related to self-reported data, are described in the Cross-sectional Survey Report.[65]

Temporality

Our findings show higher geometric means of serum PFAS concentrations in people who lived in Katherine, Oakey and Williamtown for a longer period of time, which reflects cumulative exposure to PFAS in our study population. However, due to the cross-sectional design of our study, we are unable to make statements about PFAS exposure in the past. In addition, our study population included current and previous residents and workers of the PFAS Management Areas, who may have experienced different ongoing exposures to PFAS, as well as potentially different levels of PFAS in the environments of Katherine, Oakey and Williamtown. Our estimates of associations between elevated serum PFAS concentrations and risk factors of exposure to PFAS attenuated in sensitivity analyses restricted to people who lived in the PFAS Management Areas within 5, 10 and 15 years of the survey. These findings may indicate potential differences in exposure to PFAS over time in our study population. Ongoing longitudinal research (University of Queensland) on serum PFAS concentrations in residents and workers of Katherine, Oakey and Williamtown may provide additional evidence of peak time of exposure in the past.

Conclusion

Our findings provide insight into PFAS exposure in people who have ever lived or worked in Katherine, Oakey or Williamtown. This study addresses some of the concerns related to the uncertainty of PFAS exposure levels in these communities and associated health effects. Our study shows evidence of higher blood serum PFOS and PFHxS concentrations in participants from the exposed communities, consistent with the nature of the contamination in the local environments associated with historic AFFF use. We observed geometric means of serum PFOA concentrations in Katherine, Oakey and Williamtown equivalent to the background exposure levels observed in Australian communities not affected by environmental PFAS contamination. Geometric means of serum PFAS concentrations in Katherine, Oakey and Williamtown are consistent with research conducted in US communities affected by environmental contamination from AFFF use on military bases. Higher serum PFAS concentrations were observed in a Swedish population also affected by environmental contamination from AFFF; however, these differences

are likely explained by higher concentrations of PFAS in the local environment for that study population.

Our study shows the importance of examining the association of elevated serum PFAS concentrations and the exposure pathways identified in communities affected by environmental contamination, showing links between bore water ingestion and local produce consumption patterns. Notably, duration of residence was strongly associated with elevated serum PFOS and PFHxS concentrations, particularly in Katherine, which reflects cumulative exposure to PFAS over time in these communities. Our findings have important implications for the ongoing precautions to minimise PFAS exposure in Katherine, Oakey and Williamtown. The study shows encouraging results related to residents' change in consumption patterns after they became aware of the contamination. Future research can provide insight into changes in serum PFAS concentrations in these communities over time, which may show the impact of public health interventions in recent years. Examination of PFAS levels in blood serum samples of exposed populations provides important information for community members and policy makers.

Glossary

Absolute difference — the difference between two values in real terms. For example, the absolute difference between 15 and 3 is 12.

Adjustment — the modification of an estimate to account for potential confounders (see *confounding*).

Aqueous Film-Forming Foam (firefighting foam) — a highly effective flame-suppressing foam, commonly used in the aviation industry to extinguish aircraft fires.

Association — a relationship between two variables. A *positive association* is where the mean/rate of one variable tends to increase/is higher as the value of another variable increases. An *inverse association* is where the mean/rate of one variable tends to decrease/is lower as the value of another variable increases. A *null association* is where there is no relationship between two variables.

Bias — any systematic error that results in an incorrect effect estimate (see *effect estimate*).

Causal relationship — where one variable (for example, exposure) causes another (for example, a health outcome). As opposed to 'association', where one variable is related to, but does not necessarily cause, the other.

Chance/random error — some study results may reflect a true effect; however, some results can arise simply because of chance (randomness).

Comparison communities — specific communities that have similar sociodemographic characteristics to Katherine, Oakey and Williamtown.

Confidence interval — a range of probable values for an estimate. The point estimate and its confidence interval are collectively known as the interval estimate.

Confounding — occurs if the characteristics of the exposed population do not match the characteristics of the comparison population, and it is these characteristics that cause an effect (see *effect*) to be observed. This makes the effect estimate biased (see *bias*). For example, if we compare an older population to a younger population, age may be the reason why a difference in rates of disease is observed. Age is a confounding factor here unless appropriately accounted for.

Convergence — see *non-convergence.*

Crude statistic — an estimated statistic prior to any adjustments (see *adjustment*).

Effect — the influence of one condition (for example, exposure) on another (for example, a health effect).

Effect estimate/point estimate — the value of a measurement used to estimate an effect (see *effect*). For example, the ratio of geometric means, odds ratio or prevalence ratio.

Elevated blood serum PFAS concentration — blood serum PFAS concentration above the background level of exposure observed in the comparison communities, i.e., above the 95th percentile of age-specific serum PFAS concentrations in the comparison population.

Exposed communities — areas with known environmental PFAS contamination, that is, the PFAS Management Areas.

Exposed population — all individuals who lived in the exposed communities.

Exposure levels — the level of a population's exposure to PFAS. *Background levels* reflect exposure to low levels of PFAS typically seen in the general population who have not experienced high levels of exposure. *Community exposure levels* reflect exposure to high levels of PFAS through environmental contamination of residential areas located close to facilities that use or produce

PFAS. *Occupational levels* represent exposure to very high levels of PFAS through work at facilities that use or produce PFAS.

Geocoded — providing geographical coordinates corresponding to a location.

Geometric mean — the geometric mean is a measure of the central value in a set of log-transformed values, i.e., the exponential of the mean of the log-transformed values (see also *log-transformation* and *mean*). In some circumstances the mean is not an accurate measure of the central tendency of a set of values. Using the geometric mean can dampen the effect of extreme values. The geometric mean calculates the average by multiplying the set of numbers together and dividing the product by the nth root of the number of values in the set. For example the geometric mean of 25 and 65 is the square root of 25x65 = 1,625, which equals 40.

Log-transformation — a type of data transformation used to change the values from a skewed distribution to a normal distribution in order to make patterns in the data more interpretable.

Mean — the arithmetic mean or average is the central value of a set of values, i.e., the sum of the values divided by the number of values. For example, the mean of 1,2,2,2,4,4,5 is 2.85 (20 divided by 7).

Median — the midpoint of a set of values. For example, the median value of 1,2,2,**2**,4,4,5 is 2. The median can be more useful than the mean when there are many extreme values.

Misclassification — when someone or something is assigned to an incorrect category. For example, someone could be misclassified as non-Indigenous if they did not identify as Aboriginal and/or Torres Strait Islander (see also *measurement error*).

Non-convergence — when an algorithm is not able to find a solution.

Odds ratio — a measure of association between an exposure and an outcome. The odds ratio represents the odds that an outcome will occur given a particular exposure compared to the odds of the outcome occurring in the absence of that exposure.

Percentile — a score below which a certain percentage of the population falls. For example, 91% of the population falls below an IQ score of 120 (which is the 91st percentile).

PFAS Management Areas — the areas in Katherine, Oakey and Williamtown, within boundaries defined by the Australian Department of Defence, that have known PFAS contamination. All street addresses within the PFAS Management Areas are captured in the PFAS Address Database.

Prevalence — the proportion of a population with a specific characteristic during a given time period.

Regression — a statistical method used to quantify the relationship between two variables.

Selection bias — occurs when there is a systematic difference between people who are included in the study and those who are not.

Skewed — a term to describe data that is not symmetrical, for example data that has a long tail at one end.

Sociodemographic — a combination of social and demographic factors.

Socioeconomic — a combination of social and economic factors.

Standard deviation — a measure of the spread of a set of values relative to its mean. A low standard deviation means values are closer to the mean, while a large standard deviation means the values are spread over a wider range.

Standard error — the standard deviation of a sampling distribution, which measures the variability of a statistic.

Variable — a characteristic that varies among individuals. A *binary variable* is a variable where there can only be two possible values (for example, 'yes' or 'no'). For example, elevated blood serum PFAS concentration is a binary variable as person can either have an elevated level or a background level blood serum PFAS concentration. A *categorical variable* is a variable where there can only be a limited number of values. For example, firefighting foam exposure is categorical variable with three possible values 'never, 'occupational exposure' and 'community or household exposure'). A *continuous variable* is a variable whose values can take any number including decimal places. For example, serum PFAS concentration is a continuous variable.

Appendix 1

Biomarker reference ranges

Table A1-1. Biochemical marker reference ranges, provided by Sonic Healthcare

Biochemical test	Units	Biomarker reference ranges†	
		Male	Female
Cholesterol	mmol/L	13+ years: 3.9–5.5	13+ years: 3.9–5.5
HDL cholesterol	mmol/L	All ages: 0.90–1.50	All ages: 1.10–1.90
LDL cholesterol	mmol/L	All ages: <4.0	All ages: <4.0
Triglycerides	mmol/L	All ages: 0.6–2.0	All ages: 0.6–2.0
High total:HDL cholesterol ratio	mmol/L	All ages: 0–4.5	All ages: 0–4.5
Creatinine	µmol/L	16–<70 years: 60–110 70–<80 years: 60–115 80–<90 years: 60–120 90+ years: 60–125	16–<70 years: 45–85 70–<80 years: 45–90 80–<90 years: 45–95 90+ years: 45–100
eGFR	mL/min/1.73m^2	18+ years: >59	18+ years: >59
Urate (uric acid)	mmol/L	15+ years: 0.200–0.500	16+ years: 0.150–0.400
ALT	U/L	15+ years: 5–40	1+ years: 5–30
AST	U/L	10+ years: 10–40	10+ years: 10–35
GGT	U/L	15–<18 years: 5–40 18+ years: 5–50	15+ years: 5–35
ALP	U/L	16–<17 years: 70–250 17–<20 years: 60–200 20+ years: 35–110	16–<18 years: 50–135 18–<19 years: 45–120 19–<50 years: 20–105 50+ years: 30–115
Albumin	g/L	16–<50 years: 35–48 50–<80 years: 32–44 80+ years: 30–42	9–<18 years: 34–47 18–<50 years: 33–46 50–<80 years: 32–44 80+ years: 30–42
Total protein	g/L	14–<18 years: 66–82 18–<50 years: 66–83 50–<80 years: 63–80 80+ years: 61–78	14–<18 years: 65–81 18–<50 years: 64–81 50–<80 years: 63–80 80+ years: 61–78
TSH	mIU/L	0–<3 days: 11.0–46.0 3–<7 days: 1.0–25.0 7–<14 days: 0.3–10.0 14–<365 days: 0.3–6.0 1–<6 years: 0.3–5.8 6–<11 years: 0.3–4.8 11–<15 years: 0.3–5.3 15–<18 years: 0.3–4.2 18–<50 years: 0.3–3.5 50–<70 years: 0.3–4.0 70+ years: 0.3–5.0	0–<3 days: 11.0–46.0 3–<7 days: 1.0–25.0 7–<14 days: 0.3–10.0 14–<365 days: 0.3–6.0 1–<6 years: 0.3–5.8 6–<11 years: 0.3–4.8 11–<15 years: 0.3–5.3 15–<18 years: 0.3–4.2 18–<50 years: 0.3–3.5 50–<70 years: 0.3–4.0 70+ years: 0.3–5.0

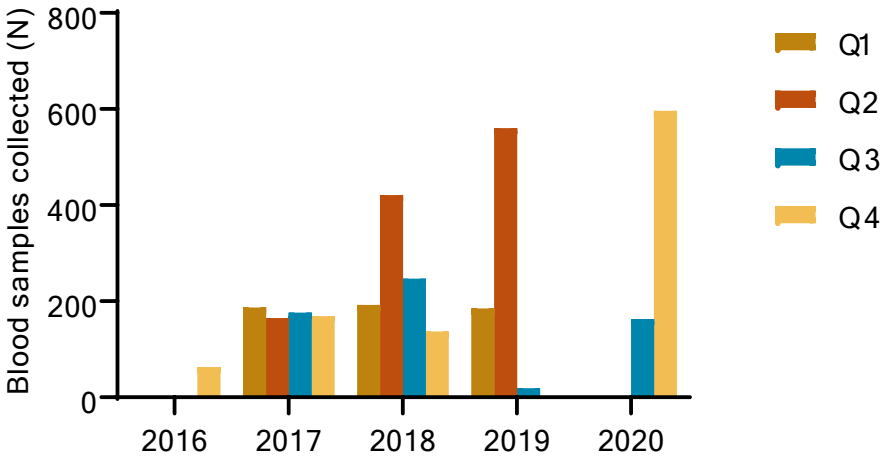
Biochemical test	Units	Biomarker reference ranges†	
		Male	Female
TSH during pregnancy	mIU/L		Gestation <6 weeks: 0.4–3.2 Gestation 6–12 weeks: 0.1–2.8 Gestation 12–18 weeks: 0.1–2.5 Gestation 12 weeks–term: 0.3–2.9
Free T3	pmol/L	0–<1 years: 4.5–8.0 1–<11 years: 4.0–7.0 11–<15 years: 3.0–7.0 15–<18 years: 3.0–6.5 18–<70 years: 2.6–6.0 70+ years: 2.3–5.7	0–<1 years: 4.5–8.0 1–<11 years: 4.0–7.0 11–<15 years: 3.0–7.0 15–<18 years: 3.0–6.5 18–<70 years: 2.6–6.0 70+ years: 2.3–5.7
Free T4	pmol/L	0–<4 days: 10.0–36.0 4–<35 days: 7.0–30.0 35–<365 days: 9.0–19.0 1–<70 years: 9.0–19.0 70+ years: 10.0–20.0	0–<4 days: 10.0–36.0 4–<35 days: 7.0–30.0 35–<365 days: 9.0–19.0 1–<70 years: 9.0–19.0 70+ years: 10.0–20.0
Free T4 during pregnancy			Gestation <6 weeks: 11–17 Gestation 6–12 weeks: 11–19 Gestation 12–18 weeks: 10–16 Gestation 12 weeks–term: 9–14

† Reference ranges provided by Sonic Healthcare.

Appendix 2

Participation in the Blood Serum Study

Figure A2-1. Blood serum sample collection over time for the Blood Serum Study from residents and workers of PFAS Management Areas, 2016–2019, and residents of comparison communities, 2020.



The coloured bars show the number of blood serum samples collected over the study period.

Table A2-1. Summary of demographic characteristics of current residents of PFAS Management Areas, 2016–2019.

	Katherine, NT	Oakey, Qld	Williamtown, NSW
Demographic characteristic	Current resident % (N)	Current resident % (N)	Current resident % (N)
Total sample	472	89	256
Age (years)			
≥15	10% (49)	3% (3)	8% (20)
16–29	9% (43)	6% (5)	16% (40)
30–49	34% (162)	19% (17)	20% (15)
50–69	36% (170)	44% (39)	41% (105)
≥70	11% (50)	28% (25)	15% (39)
Missing	0% (0)	0% (0)	<1% (1)
Sex			
Male	46% (217)	55% (49)	48% (124)
Female	54% (256)	45% (40)	52% (132)
Missing	<1% (1)	0% (0)	0% (0)
Aboriginal or Torres Strait Islander person			
No	23% (108)	36% (32)	27% (68)
Yes	3% (16)	1% (1)	<1% (1)
Missing	74% (350)	63% (56)	73% (187)

N: sample size.

Table A2-2. Summary of demographic characteristics of current exposed participants of PFAS Management Areas, 2016–2019 and Australian Census data of the general population, 2016.

	Katherine, NT		Oakey, Qld		Williamtown, NSW	
Demographic characteristic	Blood Serum Study	General population	Blood Serum Study	General population	Blood Serum Study	General population
Population size (n)	472	6,303	89	4,705	256	885
Male (%)	54	51	45	52	48	56
Median age (years old)	48	32	63	38	53	48
Aboriginal and Torres Strait Islander Persons (%)	3.38	25	0	9	0	2

Population data sourced from 2016 Census QuickStats.[67]

Appendix 3

Serum PFAS concentrations

Table A3-1. Summary of blood serum PFAS concentrations of residents and workers of PFAS Management Areas by residence/work status, 2016–2020.

	Katherine, NT		Oakey, Qld		Williamtown, NSW	
PFAS	Ever Exposed (ng/mL)	Current Residents (ng/mL)	Ever Exposed (ng/mL)	Current Residents (ng/mL)	Ever Exposed (ng/mL)	Current Residents (ng/mL)
Total sample†	1,181	472	408	89	1,121	256
PFOS						
Geometric mean (95% CI)	4.88 (4.63,5.15)	5.69 (5.26,6.16)	6.64 (5.96,7.40)	13.43 (9.82,18.3)	5.14 (4.88,5.42)	6.43 (5.72,7.21)
Median	4.76	5.57	6.09	11.50	5.03	5.94
P25	2.72	3.23	3.27	5.25	3.06	3.61
P75	7.76	9.08	11.18	35.9	8.15	10.9
Maximum	404	404	447	447	447	119
PFHxS						
Geometric mean (95% CI)	3.72 (3.49,3.97)	5.14 (4.71,5.61)	3.29 (2.89,3.75)	6.20 (4.25,9.04)	2.92 (2.75,3.10)	3.19 (2.84,3.59)
Median	3.86	5.57	2.85	6.29	2.97	3.23
P25	1.90	3.21	1.38	2.00	1.53	1.79
P75	7.32	9.68	6.93	16.2	5.55	5.70
Maximum	523	523	289	289	124	42.6
PFOA						
Geometric mean (95% CI)	1.29 (1.24,1.34)	1.27 (1.19,1.35)	1.78 (1.67,1.89)	2.02 (1.78,2.29)	1.60 (1.54,1.65)	1.76 (1.65,1.89)
Median	1.33	1.39	1.90	2.10	1.66	1.86
P25	0.89	0. 87	1.23	1.35	1.11	1.29
P75	1.96	2.02	2.66	3.00	2.34	2.50
Maximum	16.1	16.1	10.5	6.91	12.6	9.80

† Total sample for ever exposed participants defined as ever living or working in the PFAS Management Area, including participants who have lived or worked across multiple PFAS Management Areas.

CI: confidence interval; P25: 25th percentile; P75: 75th percentile.

Table A3-2. Summary of blood serum PFOS concentrations of residents and workers of PFAS Management Areas, 2016–2020, and residents of comparison communities, 2020.

	Katherine and Alice Springs, NT		Oakey and Dalby, Qld		Williamtown and Kiama and Shellharbour, NSW	
PFAS	Exposed (ng/mL)	Comparison (ng/mL)	Exposed (ng/mL)	Comparison (ng/mL)	Exposed (ng/mL)	Comparison (ng/mL)
Total sample†	1,180	171	395	150	1,016	372
Linear PFOS						
Geometric mean (95% CI)	2.72 (2.59,2.86)	1.35 (1.21,1.51)	2.91 (2.62,3.24)	1.51 (1.35,1.69)	2.79 (2.64,2.95)	1.79 (1.67,1.93)
Median	2.65	1.40	2.97	1.48	2.71	1.75
P25	1.63	0.82	1.69	0.94	1.71	1.15
P75	4.38	2.21	4.98	2.36	4.51	3.06
Maximum	57.2	8.00	287	7.50	51.0	17.5
Branched PFOS						
Geometric mean (95% CI)	1.81 (1.71,1.92)	1.35 (1.23,1.49)	3.04 (2.73,3.38)	1.68 (1.50,1.87)	2.02 (1.91,2.14)	1.75 (1.63,1.87)
Median	1.80	1.29	2.79	1.86	2.10	1.82
P25	0.80	0.77	1.36	0.98	1.00	1.02
P75	3.22	2.28	5.26	2.85	3.50	2.81
Maximum	43.1	16.8	53.3	11.3	46.5	8.47
1-methyl PFOS						
Geometric mean (95% CI)	0.44 (0.42,0.46)	0.32 (0.29,0.35)	0.71 (0.63,0.80)	0.40 (0.36,0.44)	0.45 (0.42,0.47)	0.38 (0.36,0.41)
Median	0.38	0.21	0.58	0.37	0.40	0.34
P25	0.21	0.21	0.21	0.31	0.21	0.21
P75	0.67	0.50	1.21	0.66	0.68	0.62
Maximum	30.3	9.46	26.4	2.36	29.4	2.06
Other-methyl PFOS						
Geometric mean (95% CI)	1.37 (1.29,1.44)	0.79 (0.69,0.90)	2.03 (1.83,2.27)	1.00 (0.86,1.16)	1.55 (1.46,1.64)	1.10 (1.01,1.20)
Median	1.42	0.86	2.15	1.13	1.67	1.24
P25	0.75	0.40	1.10	0.57	0.91	0.61
P75	2.50	1.56	3.94	2.04	2.73	2.00
Maximum	31.4	7.11	31.3	9.93	28.7	7.54
Di-methyl PFOS						
Geometric mean (95% CI)	0.17 (0.17,0.18)	0.17 (0.16,0.17)	0.17 (0.17,0.18)	0.17 (0.16,0.17)	0.17 (0.16,0.17)	0.17 (0.16,0.17)
Median	0.16	0.16	0.16	0.16	0.16	0.16
P25	0.16	0.16	0.16	0.16	0.16	0.16
P75	0.16	0.16	0.16	0.16	0.16	0.16

	Katherine and Alice Springs, NT		Oakey and Dalby, Qld		Williamtown and Kiama and Shellharbour, NSW	
PFAS	Exposed (ng/mL)	Comparison (ng/mL)	Exposed (ng/mL)	Comparison (ng/mL)	Exposed (ng/mL)	Comparison (ng/mL)
Maximum	16.6	1.77	3.48	1.49	4.00	2.51

† Total sample for ever exposed participants defined as ever living or working in the PFAS Management Area, including participants who have lived or worked across multiple PFAS Management Areas.

CI: confidence interval; P25: 25th percentile; P75: 75th percentile.

Table A3-3. Summary of blood serum PFAS concentrations of residents and workers of PFAS Management Areas who have lived in multiple Areas, 2016–2020.

	PFOS	PFHxS	PFOA
Summary statistic	Multiple Areas† (ng/mL)	Multiple Areas† (ng/mL)	Multiple Areas† (ng/mL)
Total sample	228	228	228
Geometric mean (95% CI)	4.71 (4.20,5.28)	2.97 (2.59,3.41)	1.42 (1.32,1.52)
Median	4.70	2.83	1.37
P25	2.72	1.41	1.01
P75	7.36	5.37	2.03
Maximum	447	124	5.57

† Blood Serum Study participants who have lived in more than one PFAS Management Area.

CI: confidence interval; P25: 25th percentile; P75: 75th percentile.

Table A3-4. Summary of blood serum PFAS concentrations of residents and workers of PFAS Management Areas who were not assigned to a PFAS Management Area, 2016–2019, due to missing data.

	PFOS	PFHxS	PFOA
Summary statistic	Unknown PFAS Management Area† (ng/mL)	Unknown PFAS Management Area† (ng/mL)	Unknown PFAS Management Area† (ng/mL)
Total sample	128	128	128
Geometric mean (95% CI)	4.23 (3.66,4.90)	2.29 (1.90,2.74)	1.54 (1.39,1.71)
Median	4.61	2.16	1.62
P25	2.49	1.22	1.12
P75	6.53	3.86	2.21
Maximum	47.9	56.6	7.75

† Blood Serum Study participants unassigned to a PFAS Management Area.

CI: confidence interval; P25: 25th percentile; P75: 75th percentile.

Table A3-5. Adjusted ratios of geometric means of blood serum PFAS concentrations and demographic characteristics for residents and workers of PFAS Management Areas, 2016–2020, and residents of comparison communities, 2020. Sensitivity analysis: serum PFAS concentrations below the limit of quantification imputed using multiple imputation by chained equations.

	PFOS		PFHxS		PFOA	
PFAS	Ever exposed Adjusted RoM‡ (95% CI)	Comparison Adjusted RoM‡ (95% CI)	Ever exposed Adjusted RoM‡ (95% CI)	Comparison Adjusted RoM‡ (95% CI)	Ever exposed Adjusted RoM‡ (95% CI)	Comparison Adjusted RoM‡ (95% CI)
Total sample†	2,581	692	2,581	693	2,581	693
Age (years)						
≥15	0.92 (0.81,1.04)	NA	1.07 (0.93,1.23)	NA	1.19 (1.08,1.32)	NA
16–29	Reference		Reference		Reference	
30–49	1.25 (1.13,1.38)	1.22 (0.91,1.64)	1.09 (0.96,1.23)	1.13 (0.86,1.49)	1.04 (0.97,1.11)	1.10 (0.91,1.33)
50–69	1.76 (1.57,1.97)	1.94 (1.47,2.56)	1.70 (1.49,1.94)	1.92 (1.49,2.48)	1.33 (1.24,1.43)	1.54 (1.30,1.82)
≥70	2.32 (2.00,2.70)	2.93 (2.20,3.89)	2.03 (1.68,2.45)	2.87 (2.20,3.75)	1.64 (1.49,1.81)	1.86 (1.57,2.22)
Sex						
Male	Reference		Reference		Reference	
Female	0.72 (0.69,0.77)	0.62 (0.57,0.69)	0.67 (0.63,0.71)	0.56 (0.49,0.63)	0.80 (0.77,0.84)	0.83 (0.76,0.90)

‡ Adjusted for sex or age.

† Total sample for ever exposed participants defined as ever living or working in the PFAS Management Area, including participants who have lived or worked across multiple PFAS Management Areas.

RoM: Ratio of geometric means; CI: confidence interval; NA: not applicable.

Table A3-6. Summary of blood serum PFAS concentrations of current residents of Oakey and Williamtown PFAS Management Areas by Management Area Zone, 2016–2019.

	Oakey, Qld			Williamtown, NSW		
	Primary Zone	Secondary Zone	Broader Zone	Primary Zone	Secondary Zone	Broader Zone
PFAS	Current resident (ng/mL)	Current resident (ng/mL)	Current resident (ng/mL)	Current resident (ng/mL)	Current resident (ng/mL)	Current resident (ng/mL)
Total sample	15	22	52	39	91	126
PFOS						
Geometric mean (95% CI)	51.28 (19.47,135.02)	11.72 (6.82,20.13)	9.67 (6.71,13.92)	9.71 (6.98,13.52)	5.95 (4.86,7.27)	5.98 (5.13,6.97)
Median	71.41	13.26	8.91	8.04	5.81	5.55
P25	34.69	4.63	4.78	4.66	3.53	3.44
P75	234.00	22.58	17.06	23.42	9.50	10.83
Maximum	312.91	103.00	447.00	75.71	119.00	64.63
PFHxS						
Geometric mean (95% CI)	25.58 (10.36,63.14)	5.15 (2.38,11.13)	4.46 (2.79,7.12)	5.70 (4.19,7.75)	2.95 (2.35,3.72)	2.83 (2.47,3.23)
Median	34.84	6.65	4.06	5.18	3.19	3.02
P25	9.10	1.41	2.02	2.41	1.35	1.86
P75	66.70	14.16	8.10	14.15	5.84	4.83
Maximum	247.00	216.00	289.00	26.59	42.59	13.26
PFOA						
Geometric mean (95% CI)	2.50 (1.70,3.67)	1.69 (1.32,2.16)	2.05 (1.75,2.40)	1.91 (1.67,2.19)	1.72 (1.51,1.95)	1.76 (1.60,1.93)
Median	2.66	1.95	2.08	1.97	1.83	1.84
P25	1.68	1.19	1.38	1.33	1.32	1.18
P75	4.20	2.52	3.09	2.61	2.43	2.51
Maximum	6.91	4.74	6.54	5.95	7.49	9.80

CI: confidence interval; P25: 25th percentile; P75: 75th percentile.

Table A3-7. Adjusted ratios of geometric means of blood serum PFAS concentrations of current residents of Oakey and Williamtown PFAS Management Areas by Management Area Zone, 2016–2019.

	Oakey, Qld				Williamtown, NSW			
	Total PFOS	Branched PFOS	PFHxS	PFOA	Total PFOS	Branched PFOS	PFHxS	PFOA
	Current resident Adjusted RoM‡ (95% CI)	Current resident Adjusted RoM‡ (95% CI)	Current resident Adjusted RoM‡ (95% CI)	Current resident Adjusted RoM‡ (95% CI)	Current resident Adjusted RoM‡ (95% CI)	Current resident Adjusted RoM‡ (95% CI)	Current resident Adjusted RoM‡ (95% CI)	Current resident Adjusted RoM‡ (95% CI)
Total sample	89	85	89	89	255	197	255	255
Broader Zone	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference
Secondary Zone	1.34 (0.66,2.69)	1.26 (0.65,2.46)	1.08 (0.41,2.83)	0.86 (0.64,1.15)	0.98 (0.75,1.27)	1.02 (0.82,1.28)	1.06 (0.80,1.40)	0.98 (0.83,1.17)
Primary Zone	4.89 (1.89,12.62)	2.44 (1.13,5.26)	5.55 (2.14,14.39)	1.24 (0.85,1.81)	1.81 (1.13,2.92)	1.68 (1.02,2.76)	2.25 (1.56,3.23)	1.10 (0.93,1.31)

‡ Adjusted for sex and sex.

RoM: ratio of geometric means; CI: confidence interval.

Table A3-8. Adjusted ratios of geometric means of blood serum PFAS concentrations of current residents of Oakey and Williamtown PFAS Management Areas by Management Area Zone, 2016–2019. Sensitivity analysis: serum PFAS concentrations below the limit of quantification imputed using multiple imputation by chained equations.

	Oakey, Qld				Williamtown, NSW			
	Total PFOS	Branched PFOS	PFHxS	PFOA	Total PFOS	Branched PFOS	PFHxS	PFOA
	Current resident Adjusted RoM‡ (95% CI)	Current resident Adjusted RoM‡ (95% CI)	Current resident Adjusted RoM‡ (95% CI)	Current resident Adjusted RoM‡ (95% CI)	Current resident Adjusted RoM‡ (95% CI)	Current resident Adjusted RoM‡ (95% CI)	Current resident Adjusted RoM‡ (95% CI)	Current resident Adjusted RoM‡ (95% CI)
Total sample	89	88	89	89	255	202	255	255
Broader Zone	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference
Secondary Zone	1.34 (0.66,2.69)	1.33 (0.69,2.56)	1.08 (0.42,2.79)	0.86 (0.64,1.15)	0.98 (0.75,1.27)	0.89 (0.71,1.12)	1.05 (0.79,1.40)	0.99 (0.83,1.17)
Primary Zone	4.89 (1.89,12.62)	2.78 (1.35,5.70)	5.47 (2.13,14.08)	1.24 (0.85,1.81)	1.81 (1.13,2.92)	1.65 (0.98,2.77)	2.25 (1.56,3.23)	1.10 (0.93,1.31)

‡ Adjusted for sex and sex.

Br-PFOS: sum of branched PFOS; RoM: ratio of geometric means; CI: confidence interval.

Appendix 4

Serum PFAS concentrations in Alice Springs, Dalby and Kiama and Shellharbour

Table A4-1. Detection frequencies of blood serum PFAS concentrations of residents PFAS Health Study comparison communities, 2020.

	Alice Springs, NT	Dalby, Qld	Kiama and Shellharbour, NSW
PFAS	Comparison % (N)	Comparison % (N)	Comparison % (N)
Total sample	171	150	372
PFOS	100% (171)	99.8% (149)	99.2% (369)
PFOA	99.4% (170)	97.3% (146)	99.5% (370)
PFHxS	82.5% (141)	93.3% (140)	93.8% (349)
PFNA	47.4% (81)	52.0% (78)	55.4% (206)
PFDA	4.1% (7)	2% (3)	2.7% (10)
PFHpA	0.0% (0)	0.0% (0)	<1% (3)
PFHxA	0.0% (0)	0.0% (0)	0.0% (0)
PFBS	0.0% (0)	0.0% (0)	0.0% (0)
6:2 FTS	0.0% (0)	0.0% (0)	0.0% (0)

N: sample size.

Table A4- 2. Summary of blood serum PFAS concentrations of residents PFAS Health Study comparison communities, 2020.

	Alice Springs, NT	Dalby, Qld	Kiama and Shellharbour, NSW
PFAS	Comparison (ng/mL)	Comparison (ng/mL)	Comparison (ng/mL)
Total sample	171	150	372
PFOS			
Geometric mean (95% CI)	2.47 (2.21,2.76)	2.97 (2.63,3.35)	3.33 (3.08,3.60)
Median	2.63	3.41	3.55
P25	1.40	1.69	2.16
P75	4.50	5.11	5.81
Maximum	24.57	15.35	24.53
PFHxS			
Geometric mean (95% CI)	0.70 (0.61,0.80)	1.16 (1.00,1.35)	1.03 (0.95,1.12)
Median	0.80	1.26	1.13
P25	0.33	0.64	0.62
P75	1.23	2.16	1.74
Maximum	24.45	10.74	18.43
PFOA			
Geometric mean (95% CI)	1.22 (1.11,1.34)	1.35 (1.21,1.52)	1.31 (1.24,1.40)
Median	1.23	1.45	1.35
P25	0.76	0.83	0.88
P75	1.89	2.02	1.99
Maximum	6.17	8.86	8.16

CI: confidence interval; P25: 25th percentile; P75: 75th percentile.

Table A4-3. Adjusted ratios of geometric means of blood serum PFAS concentrations and demographic characteristics for residents of comparison communities, 2020.

	PFOS	PFHxS	PFOA
PFAS	Comparison Adjusted RoM‡ (95% CI)	Comparison Adjusted RoM‡ (95% CI)	Comparison Adjusted RoM‡ (95% CI)
Total sample	692	693	693
Age (years)			
16–29	Reference	Reference	Reference
30–49	1.23 (0.91,1.66)	1.12 (0.89,1.41)	1.10 (0.91,1.33)
50–69	1.95 (1.47,2.60)	1.87 (1.51,2.33)	1.54 (1.30,1.81)
≥70	2.95 (2.20,3.95)	2.78 (2.21,3.49)	1.86 (1.57,2.22)
Sex			
Male	Reference	Reference	Reference
Female	0.62 (0.57,0.69)	0.56 (0.50,0.63)	0.83 (0.76,0.90)

‡ Adjusted for sex and sex.

RoM: Ratio of geometric means; CI: confidence interval.

Comparing serum PFAS concentrations in the exposed and comparison communities

Table A4-4. Adjusted ratios of geometric means of blood serum PFAS concentrations for exposed and comparison participants by state and residence/work status, 2016–2020. Sensitivity analysis: serum PFAS concentrations below the limit of quantification imputed using multiple imputation by chained equations.

	Katherine and Alice Springs, NT		Oakey and Dalby, Qld		Williamtown and Kiama and Shellharbour, NSW	
PFAS	Ever exposed Adjusted RoM‡ (95% CI)	Current resident Adjusted RoM‡ (95% CI)	Ever exposed Adjusted RoM‡ (95% CI)	Current resident Adjusted RoM‡ (95% CI)	Ever exposed Adjusted RoM‡ (95% CI)	Current resident Adjusted RoM‡ (95% CI)
Total sample†	1,211	595	550	236	1,434	207
Total PFOS	2.27 (2.04,2.54)	2.67 (2.36,3.03)	2.22 (1.90,2.60)	4.00 (2.77,5.79)	1.86 (1.66,2.08)	2.41 (2.05,2.83)
Branched PFOS#	1.71 (1.57,1.87)	1.93 (1.75,2.14)	1.74 (1.52,2.00)	2.68 (1.98,3.61)	1.42 (1.30,1.54)	1.71 (1.49,1.95)
PFHxS	5.93 (5.11,6.89)	8.42 (7.16,9.90)	2.50 (2.05,3.05)	5.16 (3.35,7.96)	3.10 (2.77,3.47)	3.77 (3.21,4.43)
PFOA	1.16 (1.05,1.28)	1.15 (1.03,1.28)	1.30 (1.15,1.46)	1.37 (1.17,1.62)	1.31 (1.22,1.41)	1.50 (1.37,1.65)

‡ Adjusted for sex and sex.

† Total sample for ever exposed participants defined as ever living or working in the PFAS Management Area, including participants who have lived or worked across multiple PFAS Management Areas.

Total sample for Branched PFOS was: NT ever exposed 1,210; NT current exposed 595; Qld ever exposed 538; Qld current resident 235; NSW ever exposed 1,347; and NSW current resident 559.

RoM: Ratio of geometric means; CI: confidence interval.

Appendix 5

Elevated serum PFAS concentrations

Table A5- 1. Number and proportions of adult residents of Katherine, Williamtown and Oakey with elevated blood serum PFAS concentrations, 2016–2020.

		PFOS	PFHxS	PFOA
PFAS Management Area	Total sample† N	Elevated level % (N)	Elevated level % (N)	Elevated level % (N)
Katherine	344	34% (118)	58 % (201)	7% (23)
Oakey	158	39% (61)	47% (74)	10% (16)
Williamtown	302	35% (103)	47% (142)	8% (25)

† Total sample was defined as ever living in the PFAS Management Area, including participants who have lived across multiple PFAS Management Areas.

N: sample size.

Risk factor sensitivity analysis 1: elevated PFAS level definition

Table A5-2. 95th percentile of blood serum PFAS concentrations of residents of PFAS Health Study comparison communities by age and sex, 2016–2019.

			PFOS	PFHxS	PFOA
		Total sample† N	95th percentile (ng/mL)	95th percentile (ng/mL)	95th percentile (ng/mL)
Age (years)	Sex				
16–49	Male	53	8.17	3.25	2.80
	Female	107	4.43	1.13	2.66
50–69	Male	142	8.22	4.29	3.38
	Female	210	6.60	3.44	3.40
≥70	Male	94	12.64	4.94	4.06
	Female	86	10.54	5.48	4.17

† Total sample was defined as all participants from comparison communities.

N: sample size.

Table A5-3. Number and proportions of adult residents of PFAS Management Areas with elevated blood serum PFAS concentrations with the elevated PFAS level definition based on age and sex, 2016–2020.

		PFOS	PFHxS	PFOA
PFAS Management Area	Total sample† N	Elevated level % (N)	Elevated level % (N)	Elevated level % (N)
Katherine	344	30.2% (104)	59.3% (204)	6.7% (23)
Oakey	158	34.8% (55)	43.0% (68)	10.8% (17)
Williamtown	302	32.1% (97)	48.0% (145)	8.9% (25)

† Total sample was defined as ever living in the PFAS Management Area, including participants who have lived across multiple PFAS Management Areas.

N: sample size.

Table A5-4. Adjusted odds ratios of elevated blood serum PFAS concentrations in relation to risk factors of exposure to PFAS for adult residents of PFAS Management Areas, 2016–2020. Sensitivity analysis: elevated PFAS definition based on age and sex.

	Katherine, NT	Oakey, Qld	Williamtown, NSW
Risk factor	Adjusted OR‡ (95% CI)	Adjusted OR‡ (95% CI)	Adjusted OR‡ (95% CI)
Total sample†	327	149	287
PFOS			
Ingestion of bore water			
Infrequent or never	Reference	Reference	Reference
Frequent	1.89 (1.06,3.37)	2.59 (1.24,5.41)	0.96 (0.49,1.87)
Consumption of high-risk local produce			
Infrequent or never	Reference	Reference	Reference
Frequent	0.99 (0.58,1.68)	1.77 (0.82,3.81)	2.04 (1.12,3.71)
Exposure to firefighting foams			
Never	Reference	Reference	Reference
Community or household exposure	0.90 (0.43,1.89)	0.31 (0.06,1.55)	1.84 (0.70,4.87)
Occupational exposure	1.28 (0.67,2.46)	2.50 (0.96,6.52)	2.54 (1.22,5.29)
Residence in PFAS Management Area			
<7 years	Reference	Reference	Reference
7–16 years	1.23 (0.65,2.34)	1.77 (0.74,4.24)	1.09 (0.55,2.16)
>16 years	2.65 (1.25,5.63)	1.60 (0.58,4.38)	2.43 (1.08,5.46)
PFHxS			
Ingestion of bore water			
Infrequent or never	Reference	Reference	Reference
Frequent	1.01 (0.62,1.64)	1.70 (0.74,3.92)	0.73 (0.38,1.38)
Consumption of high-risk local produce			
Infrequent or never	Reference	Reference	Reference
Frequent	0.77 (0.45,1.32)	2.49 (1.07,5.79)	1.47 (0.91,2.37)
Exposure to firefighting foams			
Never	Reference	Reference	Reference
Community or household exposure	1.16 (0.63,2.15)	0.86 (0.25,2.95)	1.59 (0.58,4.39)
Occupational exposure	2.39 (1.02,5.59)	3.81 (1.20,12.13)	2.17 (1.17,4.04)
Residence in PFAS Management Area			
<7 years	Reference	Reference	Reference
7–16 years	2.85 (1.59,5.11)	1.70 (0.77,3.74)	1.03 (0.57,1.84)
>16 years	4.68 (2.15,10.19)	1.80 (0.62,5.21)	1.69 (0.83,3.44)
PFOA			
Ingestion of bore water			

	Katherine, NT	Oakey, Qld	Williamtown, NSW
Risk factor	Adjusted OR‡ (95% CI)	Adjusted OR‡ (95% CI)	Adjusted OR‡ (95% CI)
Infrequent or never	Reference	Reference	Reference
Frequent	1.21 (0.41,3.56)	1.47 (0.47,4.63)	1.31 (0.40,4.30)
Consumption of high-risk local produce			
Infrequent or never	Reference	Reference	Reference
Frequent	1.85 (0.63,5.44)	1.20 (0.39,3.68)	2.91 (1.03,8.23)
Exposure to firefighting foams			
Never	Reference	Reference	Reference
Community or household exposure	0.64 (0.15,2.75)	1.88 (0.35,10.21)	0.66 (0.07,5.84)
Occupational exposure	0.87 (0.24,3.13)	0.73 (0.16,3.40)	1.69 (0.58,4.93)
Residence in PFAS Management Area			
<7 years	Reference	Reference	Reference
7–16 years	1.39 (0.36,5.42)	0.40 (0.10,1.61)	0.78 (0.28,2.21)
>16 years	1.24 (0.24,6.35)	0.38 (0.08,1.69)	0.50 (0.12,2.06)

Effects are odds ratios of elevated blood serum PFAS concentrations in exposed communities for each of the assessed risk factors.

‡ Adjusted for age, sex, living in multiple PFAS Management Areas and all risk factors assessed in the model. Age was modelled using a restricted cubic spline with 3 knots.

† Total sample for adult residents who participated in the Blood Serum Study and Cross-sectional Survey, defined as ever living in the PFAS Management Area and including participants who have lived across multiple PFAS Management Areas.

N: sample size; OR: odds ratio.

Risk factor sensitivity analysis 2: exclusion of participants who have not lived in a PFAS Management Area in the past 5, 10 and 15 years

Table A5-5. Adjusted odds ratios of elevated blood serum PFAS concentration in relation to risk factors of exposure to PFAS for adult residents of PFAS Management Areas, 2016–2020. Sensitivity analysis: exclusion of participants who had not lived in the PFAS Management Areas in the past 5, 10 and 15 years.

Risk factor	Katherine, NT			Oakey, Qld			Williamtown, NSW		
	Adjusted OR‡ (95% CI)			Adjusted OR‡ (95% CI)			Adjusted OR‡ (95% CI)		
	5 years	10 years	15 years	5 years	10 years	15 years	5 years	10 years	15 years
Total sample†	287	134	231	296	135	240	303	138	246
PFOS									
Ingestion of bore water									
Infrequent or never	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference
Frequent	1.21 (0.67,2.20)	2.37 (1.12,5.02)	0.89 (0.43,1.86)	1.29 (0.71,2.32)	2.39 (1.13,5.06)	0.94 (0.45,1.95)	1.30 (0.72,2.34)	2.27 (1.08,4.78)	0.87 (0.42,1.81)
Consumption of high-risk local produce									
Infrequent or never	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference
Frequent	1.39 (0.80,2.41)	1.60 (0.73,3.52)	2.04 (1.06,3.93)	1.36 (0.79,2.34)	1.62 (0.74,3.56)	1.89 (0.99,3.58)	1.34 (0.78,2.31)	1.70 (0.78,3.73)	1.86 (0.97,3.54)
Exposure to firefighting foams									
Never	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference
Community or household exposure	1.30 (0.59,2.88)	0.49 (0.11,2.18)	2.27 (0.79,6.56)	1.27 (0.59,2.72)	0.49 (0.11,2.19)	2.32 (0.80,6.71)	1.25 (0.58,2.69)	0.46 (0.10,2.04)	2.11 (0.74,6.03)
Occupational exposure	1.07 (0.56,2.01)	2.18 (0.87,5.46)	2.03 (0.97,4.27)	1.04 (0.55,1.95)	2.17 (0.86,5.45)	1.99 (0.95,4.17)	1.06 (0.56,2.00)	2.28 (0.91,5.71)	2.04 (0.97,4.28)
Residence in PFAS Management Area									
<7 years	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference

Risk factor	Katherine, NT			Oakey, Qld			Williamtown, NSW		
	Adjusted OR‡ (95% CI)			Adjusted OR‡ (95% CI)			Adjusted OR‡ (95% CI)		
	5 years	10 years	15 years	5 years	10 years	15 years	5 years	10 years	15 years
7–16 years	1.04 (0.55,1.95)	1.60 (0.63,4.04)	1.01 (0.48,2.15)	1.03 (0.55,1.93)	1.55 (0.62,3.85)	1.02 (0.48,2.14)	1.05 (0.56,1.95)	1.52 (0.62,3.72)	1.00 (0.48,2.11)
>16 years	2.08 (0.97,4.44)	1.90 (0.68,5.32)	2.85 (1.16,7.03)	2.14 (1.00,4.57)	1.87 (0.67,5.26)	2.87 (1.18,6.99)	2.27 (1.07,4.82)	1.71 (0.61,4.79)	2.76 (1.13,6.72)
PFHxS									
Ingestion of bore water									
Infrequent or never	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference
Frequent	1.07 (0.58,1.97)	2.35 (1.07,5.18)#	0.57 (0.28,1.18)#	1.20 (0.64,2.24)	2.36 (1.07,5.23)	0.58 (0.29,1.18)	1.21 (0.65,2.26)	2.52 (1.14,5.60)	0.55 (0.27,1.12)
Consumption of high-risk local produce									
Infrequent or never	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference
Frequent	1.00 (0.55,1.85)	2.00 (0.95,4.21)#	2.03 (1.12,3.68)#	1.15 (0.65,2.03)	2.03 (0.96,4.29)	1.92 (1.10,3.38)	1.10 (0.63,1.92)	1.99 (0.94,4.24)	1.91 (1.08,3.36)
Exposure to firefighting foams									
Never	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference
Community or household exposure	1.13 (0.46,2.75)	0.66 (0.16,2.72)#	3.26 (1.03,10.36)#	1.19 (0.47,3.00)	0.67 (0.16,2.76)	3.45 (1.09,10.92)	1.13 (0.45,2.84)	0.60 (0.15,2.45)	2.87 (0.95,8.69)
Occupational exposure	1.31 (0.61,2.84)	1.00 (0.48,2.09)#	1.89 (0.94,3.82)#	1.09 (0.52,2.27)	1.00 (0.48,2.08)	2.01 (1.00,4.05)	1.14 (0.54,2.39)	0.98 (0.46,2.05)	2.10 (1.05,4.23)
Residence in PFAS Management Area									
<7 years	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference
7–16 years	2.22 (1.20,4.14)	0.74 (0.27,2.02) #	0.86 (0.44,1.69)#	1.98 (1.08,3.64)	0.71 (0.26,1.90)	0.87 (0.45,1.70)	2.02 (1.11,3.67)	0.71 (0.27,1.86)	0.86 (0.45,1.67)
>16 years	7.87 (2.94,21.08)	1.32 (0.49,3.51) #	1.86 (0.79,4.35)#	6.26 (2.35,16.70)	1.29 (0.48,3.41)	1.99 (0.87,4.58)	7.11 (2.65,19.10)	1.35 (0.51,3.60)	1.92 (0.84,4.39)

Risk factor	Katherine, NT			Oakey, Qld			Williamtown, NSW		
	Adjusted OR‡ (95% CI)			Adjusted OR‡ (95% CI)			Adjusted OR‡ (95% CI)		
	5 years	10 years	15 years	5 years	10 years	15 years	5 years	10 years	15 years
PFOA									
Ingestion of bore water									
Infrequent or never	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference
Frequent ingestion	1.15 (0.35,3.71)	0.87 (0.22,3.37)	2.14 (0.59,7.77)	1.01 (0.31,3.25)	0.88 (0.23,3.40)	1.69 (0.46,6.15)	1.24 (0.41,3.74)	0.81 (0.20,3.33)	1.68 (0.47,5.99)
Consumption of high-risk local produce									
Infrequent or never	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference
Frequent	1.75 (0.58,5.26)	1.16 (0.32,4.16)	5.68 (1.40,23.05)	2.04 (0.66,6.36)	1.17 (0.33,4.16)	5.69 (1.41,23.00)	2.30 (0.73,7.22)	1.27 (0.35,4.60)	5.69 (1.41,23.00)
Exposure to firefighting foams									
Never	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference
Community or household exposure	0.85 (0.19,3.80)	NC	1.03 (0.11,9.83)	0.71 (0.16,3.13)	NC	0.95 (0.11,8.51)	0.64 (0.14,2.81)	NC	0.88 (0.10,7.86)
Occupational exposure	0.80 (0.21,3.03)	0.75 (0.11,4.91)	2.14 (0.57,8.02)	0.65 (0.17,2.48)	0.74 (0.12,4.81)	1.75 (0.48,6.36)	0.67 (0.18,2.53)	0.73 (0.11,4.70)	1.77 (0.48,6.47)
Residence in PFAS Management Area									
<7 years	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference
7–16 years	1.38 (0.32,5.95)	0.69 (0.12,4.18)	0.79 (0.22,2.83)	1.56 (0.37,6.52)	0.66 (0.11,3.91)	1.00 (0.29,3.44)	1.09 (0.27,4.38)	0.64 (0.10,3.93)	0.99 (0.29,3.43)
>16 years	1.32 (0.25,7.09)	1.11 (0.26,4.79)	0.71 (0.14,3.70)	1.37 (0.26,7.35)	1.10 (0.26,4.68)	0.76 (0.16,3.65)	0.90 (0.17,4.63)	1.05 (0.24,4.66)	0.74 (0.15,3.62)

Effects are odds ratios of elevated blood serum PFAS concentrations in exposed communities for each of the assessed risk factors.

‡ Adjusted for age, sex, living in multiple PFAS Management Areas and all risk factors assessed in the model. Age was modelled using a restricted cubic spline with 3 knots.

† Total sample for adult residents who participated in the Blood Serum Study and Cross-sectional Survey, defined as ever living in the PFAS Management Area and including participants who have lived across multiple PFAS Management Areas.

Estimated assuming an independence (rather than exchangeable) within-cluster correlation structure and cluster-robust standard errors.
N: sample size; OR: odds ratio.

Risk factor sensitivity analysis 3: exclusion of participants who have not lived in a PFAS Management Area for at least one year

Table A5-6. Adjusted odds ratios of elevated blood serum PFAS concentration in relation to risk factors of exposure to PFAS for adult residents of PFAS Management Areas, 2016–2020. Sensitivity analysis: exclusion of participants who had not lived in the PFAS Management Areas for at least one year.

	Katherine, NT	Oakey, Qld	Williamtown, NSW
Risk factor	Adjusted OR‡ (95% CI)	Adjusted OR‡ (95% CI)	Adjusted OR‡ (95% CI)
Total sample†	323	146	285
PFOS			
Ingestion of bore water			
Infrequent or never	Reference	Reference	Reference
Frequent	1.22 (0.68,2.19)	2.75 (1.33,5.70)	0.87 (0.45,1.71)
Consumption of high-risk local produce			
Infrequent or never	Reference	Reference	Reference
Frequent	1.38 (0.80,2.37)	1.77 (0.82,3.83)	1.83 (1.02,3.28)
Exposure to firefighting foams			
Never	Reference	Reference	Reference
Community or household exposure	1.04 (0.50,2.15)	0.55 (0.16,1.88)	2.38 (0.92,6.17)
Occupational exposure	1.10 (0.59,2.06)	2.26 (0.90,5.70)	1.87 (0.93,3.74)
Residence in PFAS Management Area			
<7 years	Reference	Reference	Reference
7–16 years	1.00 (0.54,1.85)	1.55 (0.65,3.69)	1.07 (0.54,2.12)
>16 years	2.47 (1.18,5.17)	1.60 (0.59,4.29)	2.63 (1.17,5.95)
PFHxS			
Ingestion of bore water			
Infrequent or never	Reference	Reference	Reference
Frequent	1.09 (0.63,1.88)	2.72 (1.27,5.83)	0.59 (0.31,1.15)
Consumption of high-risk local produce			
Infrequent or never	Reference	Reference	Reference
Frequent	0.83 (0.45,1.52)	2.01 (0.96,4.20)	2.05 (1.21,3.50)
Exposure to firefighting foams			
Never	Reference	Reference	Reference
Community or household exposure	0.94 (0.44,1.99)	0.67 (0.20,2.25)	2.18 (0.84,5.61)
Occupational exposure	1.73 (0.78,3.86)	1.03 (0.49,2.15)	2.09 (1.06,4.11)
Residence in PFAS Management Area			
<7 years	Reference	Reference	Reference
7–16 years	1.95 (1.03,3.72)	0.73 (0.27,1.97)	0.90 (0.49,1.67)
>16 years	7.52 (2.90,19.53)	1.38 (0.54,3.51)	1.96 (0.91,4.22)
PFOA			
Ingestion of bore water			
Infrequent or never	Reference	Reference	Reference
Frequent	1.19 (0.41,3.48)	2.42 (0.94,6.27)	1.29 (0.39,4.25)

Risk factor	Katherine, NT Adjusted OR‡ (95% CI)	Oakey, Qld Adjusted OR‡ (95% CI)	Williamtown, NSW Adjusted OR‡ (95% CI)
Consumption of high-risk local produce			
Infrequent or never	Reference	Reference	Reference
Frequent	1.89 (0.64,5.61)	0.75 (0.27,2.10)	2.98 (1.06,8.43)
Exposure to firefighting foams			
Never	Reference	Reference	Reference
Community or household exposure	0.63 (0.15,2.73)	0.70 (0.08,6.21)	0.64 (0.07,5.81)
Occupational exposure	0.85 (0.24,3.05)	0.81 (0.18,3.63)	1.66 (0.57,4.84)
Residence in PFAS Management Area			
<7 years	Reference	Reference	Reference
7–16 years	1.33 (0.34,5.24)	0.51 (0.16,1.64)	0.76 (0.27,2.15)
>16 years	1.16 (0.22,6.14)	0.44 (0.10,1.90)	0.47 (0.11,1.98)

Effects are odds ratios of elevated blood serum PFAS concentrations in exposed communities for each of the assessed risk factors.

‡ Adjusted for age, sex, living in multiple PFAS Management Areas and all risk factors assessed in the model. Age was modelled using a restricted cubic spline with 3 knots.

† Total sample for adult residents who participated in the Blood Serum Study and Cross-sectional Survey, defined as ever living in the PFAS Management Area and including participants who have lived across multiple PFAS Management Areas.

N: sample size; OR: odds ratio.

Risk factor sensitivity analysis 4: inclusion of PFAS elimination pathways

Table A5-7. Adjusted odds ratios of elevated blood serum PFAS concentration in relation to risk factors of exposure to PFAS for adult residents of PFAS Management Areas, 2016–2020. Sensitivity analysis: Inclusion of PFAS elimination pathways.

	Katherine, NT	Oakey, Qld	Williamtown, NSW
Risk factor	Adjusted OR‡ (95% CI)	Adjusted OR‡ (95% CI)	Adjusted OR‡ (95% CI)
Total sample†	327	148	284
PFOS			
Ingestion of bore water			
Infrequent or never	Reference	Reference	Reference
Frequent	1.26 (0.70,2.26)	2.45 (1.12,5.37)	0.82 (0.41,1.63)
Consumption of high-risk local produce			
Infrequent or never	Reference	Reference	Reference
Frequent	1.32 (0.76,2.27)	1.60 (0.73,3.49)	1.77 (0.98,3.22)
Exposure to firefighting foams			
Never	Reference	Reference	Reference
Community or household exposure	1.09 (0.52,2.32)	0.52 (0.15,1.78)	2.27 (0.84,6.17)
Occupational exposure	1.27 (0.67,2.40)	2.07 (0.82,5.23)	1.82 (0.91,3.67)
Residence in PFAS Management Area			
<7 years	Reference	Reference	Reference
7–16 years	1.11 (0.60,2.06)	1.41 (0.60,3.35)	1.10 (0.56,2.17)
>16 years	2.95 (1.41,6.17)	1.46 (0.52,4.05)	2.64 (1.18,5.92)
Blood donation			
Never donation	Reference	Reference	Reference
Ever donation	0.62 (0.37,1.04)	1.03 (0.48,2.22)	0.57 (0.33,0.99)
Blood transfusion			
Never transfusion	Reference	Reference	Reference
Ever transfusion	1.75 (0.32,9.53)	2.05 (0.27,15.71)	0.96 (0.26,3.59)
Breastfeeding			
Never breastfed infant	Reference	Reference	Reference
Ever breastfed infant	0.78 (0.35,1.73)	0.84 (0.24,2.93)	1.10 (0.41,2.94)
PFHxS			
Ingestion of bore water			
Infrequent or never	Reference	Reference	Reference
Frequent	1.19 (0.68,2.08)	2.74 (1.24,6.04)	0.59 (0.30,1.16)
Consumption of high-risk local produce			
Infrequent or never	Reference	Reference	Reference
Frequent	0.79 (0.43,1.43)	1.78 (0.83,3.84)	2.01 (1.17,3.45)
Exposure to firefighting foams			
Never	Reference	Reference	Reference
Community or household exposure	0.98 (0.45,2.15)	0.57 (0.16,2.00)	3.10 (1.09,8.83)
Occupational exposure	2.05 (0.89,4.71)	0.94 (0.42,2.14)	2.11 (1.03,4.31)
Residence in PFAS Management Area			

Risk factor	Katherine, NT Adjusted OR‡ (95% CI)	Oakey, Qld Adjusted OR‡ (95% CI)	Williamtown, NSW Adjusted OR‡ (95% CI)
<7 years	Reference	Reference	Reference
7–16 years	2.25 (1.17,4.34)	0.82 (0.33,2.04)	1.03 (0.54,1.96)
>16 years	10.53 (4.22,26.25)	1.40 (0.53,3.70)	1.99 (0.92,4.31)
Blood donation			
Never donation	Reference	Reference	Reference
Ever donation	0.48 (0.29,0.79)	0.73 (0.34,1.58)	0.45 (0.26,0.77)
Blood transfusion			
Never transfusion	Reference	Reference	Reference
Ever transfusion	1.44 (0.20,10.52)	2.38 (0.19,29.16)	1.00 (0.37,2.70)
Breastfeeding			
Never breastfed infant	Reference	Reference	Reference
Ever breastfed infant	0.64 (0.29,1.42)	1.10 (0.28,4.29)	0.55 (0.21,1.42)
PFOA			
Ingestion of bore water			
Infrequent or never	Reference	Reference	Reference
Frequent	1.28 (0.44,3.67)	2.12 (0.68,6.62)	1.33 (0.39,4.48)
Consumption of high-risk local produce			
Infrequent or never	Reference	Reference	Reference
Frequent	2.00 (0.65,6.11)	0.97 (0.33,2.89)	3.17 (1.11,9.06)
Exposure to firefighting foams			
Never	Reference	Reference	Reference
Community or household exposure	0.67 (0.16,2.90)	0.77 (0.08,7.31)	0.84 (0.09,7.86)
Occupational exposure	0.92 (0.24,3.54)	0.81 (0.18,3.68)	1.92 (0.63,5.83)
Residence in PFAS Management Area			
<7 years	Reference	Reference	Reference
7–16 years	1.42 (0.35,5.71)	0.53 (0.14,2.01)	0.73 (0.25,2.12)
>16 years	1.35 (0.25,7.38)	0.39 (0.10,1.52)	0.48 (0.11,2.02)
Blood donation			
Never donation	Reference	Reference	Reference
Ever donation	0.55 (0.20,1.56)	1.11 (0.42,2.97)	1.08 (0.43,2.71)
Blood transfusion			
Never transfusion	Reference	Reference	Reference
Ever transfusion	NC	NC	NC
Breastfeeding			
Never breastfed infant	Reference	Reference	Reference
Ever breastfed infant	0.35 (0.03,4.10)	4.15 (0.63,27.20)	1.12 (0.17,7.19)

Effects are odds ratios of elevated blood serum PFAS concentrations in exposed communities for each of the assessed risk factors.

‡ Adjusted for age, sex, living in multiple PFAS Management Areas and all risk factors assessed in the model. Age was modelled using a restricted cubic spline with 3 knots.

† Total sample for adult residents who participated in the Blood Serum Study and Cross-sectional Survey, defined as ever living in the PFAS Management Area and including participants who have lived across multiple PFAS Management Areas.

N: sample size; OR: odds ratio.

Risk factor sensitivity analysis 5: inclusion of all types of bore water exposure

Table A5-8. Adjusted odds ratios of elevated blood serum PFAS concentration in relation to risk factors of exposure to PFAS for adult residents of PFAS Management Areas, 2016–2020. Sensitivity analysis: Inclusion of a broader definition of bore water exposure.

	Katherine, NT	Oakey, Qld	Williamtown, NSW
Risk factor	Adjusted OR‡ (95% CI)	Adjusted OR‡ (95% CI)	Adjusted OR‡ (95% CI)
Total sample†	327	149	287
PFOS			
Exposure to bore water			
Infrequent or never	Reference	Reference	Reference
Frequent	1.46 (0.81,2.63)	2.08 (1.01,4.28)	1.55 (0.82,2.91)
Consumption of high-risk local produce			
Infrequent or never	Reference	Reference	Reference
Frequent	1.31 (0.76,2.23)	1.76 (0.82,3.78)	1.67 (0.92,3.01)
Exposure to firefighting foams			
Never	Reference	Reference	Reference
Community or household exposure	1.05 (0.51,2.20)	0.61 (0.18,2.07)	2.28 (0.87,5.97)
Occupational exposure	1.17 (0.62,2.19)	2.29 (0.93,5.61)	1.95 (0.98,3.87)
Residence in PFAS Management Area			
<7 years	Reference	Reference	Reference
7–16 years	1.06 (0.58,1.94)	1.44 (0.62,3.35)	1.00 (0.50,1.98)
>16 years	2.68 (1.29,5.61)	1.35 (0.49,3.66)	2.27 (0.98,5.25)
PFHxS			
Exposure to bore water			
Infrequent or never	Reference	Reference	Reference
Frequent	1.46 (0.75,2.85)	2.06 (0.98,4.33)	1.09 (0.59,2.01)
Consumption of high-risk local produce			
Infrequent or never	Reference	Reference	Reference
Frequent	0.80 (0.44,1.44)	1.98 (0.95,4.12)	1.93 (1.12,3.31)
Exposure to firefighting foams			
Never	Reference	Reference	Reference
Community or household exposure	0.93 (0.44,1.99)	0.70 (0.21,2.40)	2.07 (0.80,5.36)
Occupational exposure	1.81 (0.82,3.97)	1.07 (0.50,2.25)	2.19 (1.13,4.25)
Residence in PFAS Management Area			
<7 years	Reference	Reference	Reference
7–16 years	2.04 (1.09,3.80)	0.76 (0.30,1.90)	0.88 (0.48,1.65)
>16 years	8.30 (3.29,20.96)	1.21 (0.47,3.12)	1.82 (0.84,3.95)
PFOA			
Exposure to bore water			
Infrequent or never	Reference	Reference	Reference
Frequent	1.73 (0.66,4.55)	2.61 (1.00,6.77)	1.31 (0.46,3.78)

Risk factor	Katherine, NT Adjusted OR‡ (95% CI)	Oakey, Qld Adjusted OR‡ (95% CI)	Williamtown, NSW Adjusted OR‡ (95% CI)
Consumption of high-risk local produce			
Infrequent or never	Reference	Reference	Reference
Frequent	1.74 (0.60,5.03)	0.76 (0.28,2.08)	2.82 (1.01,7.89)
Exposure to firefighting foams			
Never	Reference	Reference	Reference
Community or household exposure	0.64 (0.15,2.79)	0.77 (0.09,6.61)	0.66 (0.07,6.10)
Occupational exposure	0.90 (0.25,3.26)	0.95 (0.21,4.20)	1.69 (0.58,4.97)
Residence in PFAS Management Area			
<7 years	Reference	Reference	Reference
7–16 years	1.30 (0.33,5.08)	0.49 (0.15,1.56)	0.77 (0.28,2.12)
>16 years	1.15 (0.23,5.83)	0.39 (0.10,1.62)	0.48 (0.11,2.05)

Effects are odds ratios of elevated blood serum PFAS concentrations in exposed communities for each of the assessed risk factors.

‡ Adjusted for age, sex, living in multiple PFAS Management Areas and all risk factors assessed in the model. Age was modelled using a restricted cubic spline with 3 knots.

† Total sample for adult residents who participated in the Blood Serum Study and Cross-sectional Survey, defined as ever living in the PFAS Management Area and including participants who have lived across multiple PFAS Management Areas.

N: sample size; OR: odds ratio.

Risk factor secondary analysis: continuous serum PFAS concentrations

Table A5-9. Adjusted ratios of geometric means of blood serum PFAS concentration in relation to risk factors of exposure to PFAS for adult residents of PFAS Management Areas, 2016–2020. Secondary analysis: continuous serum PFAS concentrations.

	Katherine, NT	Oakey, Qld	Williamtown, NSW
Risk factor	Adjusted RoM‡ (95% CI)	Adjusted RoM‡ (95% CI)	Adjusted RoM‡ (95% CI)
Total sample†	327	149	287
PFOS			
Ingestion of bore water			
Infrequent or never	Reference	Reference	Reference
Frequent	1.16 (0.91,1.49)	1.40 (0.96,2.04)	0.88 (0.66,1.17)
Consumption of high-risk local produce			
Infrequent or never	Reference	Reference	Reference
Frequent	1.08 (0.86,1.34)	1.27 (0.84,1.92)	1.22 (1.00,1.51)
Exposure to firefighting foams			
Never	Reference	Reference	Reference
Community or household exposure	0.94 (0.73,1.22)	0.73 (0.44,1.21)	1.13 (0.76,1.69)
Occupational exposure	1.00 (0.77,1.30)	1.03 (0.69,1.53)	1.28 (0.95,1.71)
Residence in PFAS Management Area			
<7 years	Reference	Reference	Reference
7–16 years	1.26 (0.98,1.63)	0.98 (0.74,1.31)	1.09 (0.87,1.36)
>16 years	1.60 (1.17,2.19)	0.93 (0.58,1.48)	1.46 (1.03,2.06)
PFHxS			
Ingestion of bore water			
Infrequent or never	Reference	Reference	Reference
Frequent	1.12 (0.82,1.51)	1.75 (1.18,2.59)	0.90 (0.66,1.22)
Consumption of high-risk local produce			
Infrequent or never	Reference	Reference	Reference
Frequent	1.07 (0.83,1.37)	1.26 (0.83,1.90)	1.18 (0.92,1.51)
Exposure to firefighting foams			
Never	Reference	Reference	Reference
Community or household exposure	0.95 (0.68,1.33)	0.75 (0.44,1.27)	1.32 (0.77,2.26)
Occupational exposure	1.06 (0.78,1.44)	1.18 (0.76,1.83)	1.59 (1.20,2.10)
Residence in PFAS Management Area			
<7 years	Reference	Reference	Reference

Risk factor	Katherine, NT Adjusted RoM‡ (95% CI)	Oakey, Qld Adjusted RoM‡ (95% CI)	Williamtown, NSW Adjusted RoM‡ (95% CI)
7–16 years	1.61 (1.22,2.12)	1.16 (0.82,1.65)	1.17 (0.89,1.53)
>16 years	3.09 (2.06,4.61)	1.38 (0.82,2.31)	1.51 (1.04,2.19)
PFOA			
Ingestion of bore water			
Infrequent or never	Reference	Reference	Reference
Frequent	0.96 (0.82,1.12)	1.15 (0.95,1.40)	0.95 (0.80,1.14)
Consumption of high-risk local produce			
Infrequent or never	Reference	Reference	Reference
Frequent	1.08 (0.94,1.23)	0.97 (0.79,1.19)	1.13 (0.98,1.31)
Exposure to firefighting foams			
Never	Reference	Reference	Reference
Community or household exposure	1.04 (0.88,1.23)	0.84 (0.58,1.22)	1.01 (0.80,1.27)
Occupational exposure	0.92 (0.77,1.11)	0.95 (0.75,1.21)	1.11 (0.94,1.30)
Residence in PFAS Management Area			
<7 years	Reference	Reference	Reference
7–16 years	0.98 (0.84,1.14)	0.87 (0.70,1.07)	0.91 (0.77,1.07)
>16 years	0.95 (0.78,1.15)	0.82 (0.62,1.08)	1.05 (0.86,1.27)

Effects are ratios of geometric means of blood serum PFAS concentrations in exposed communities for each of the assessed risk factors.

‡ Adjusted for age, sex, living in multiple PFAS Management Areas and all risk factors assessed in the model. Age was modelled using a restricted cubic spline with 3 knots.

† Total sample for adult residents who participated in the Blood Serum Study and Cross-sectional Survey, defined as ever living in the PFAS Management Area and including participants who have lived across multiple PFAS Management Areas.

N: sample size; RoM: ratio of geometric means.

Appendix 6

Biochemical markers

Table A6-1. Crude prevalence ratios of adverse lipid concentrations and liver, kidney and thyroid function biomarker concentrations for residents and workers of PFAS Management Areas, 2016–2020.

	Katherine, NT		Oakey, Qld		Williamtown, NSW	
	N	Prevalence % (cases/N)	N	Prevalence % (cases/N)	N	Prevalence % (cases/N)
High total cholesterol (>5.5 mmol/L)	354	35.0% (124/354)	205	32.2% (66/205)	396	35.4% (140/396)
Low HDL cholesterol^	354	10.7% (38/354)	205	9.3% (19/205)	396	8.1% (32/396)
High LDL cholesterol (>4 mmol/L)	335	14.9% (50/335)	205	12.2% (25/205)	389	14.1% (55/389)
High total:HDL cholesterol ratio (>4.5 mmol/L)	354	24.6% (87/354)	205	29.3% (60/205)	396	26.8% (106/396)
High triglycerides (>2 mmol/L)	353	30.9% (109/353)	205	43.4% (89/205)	396	35.1% (139/396)
High serum creatinine^	354	2.8% (10/354)	205	6.8% (14/205)	396	2.5% (10/396)
High urate (uric acid)^	354	7.9% (28/354)	205	5.9% (12/205)	396	8.3% (33/396)
Low eGFR (<60 mL/min/1.73 m2) CKD-EPI formula	350	2.6% (9/350)	204	4.9% (10/204)	393	3.1% (12/393)
High ALT^	322	5.3% (17/322)	203	5.4% (11/203)	388	5.4% (21/388)
High AST^	351	3.1% (11/351)	205	4.4% (9/205)	395	2.0% (8/395)
High GGT^	354	14.1% (50/354)	205	19.0% (39/205)	396	16.9% (67/396)
High ALP^	354	5.1% (18/354)	205	4.9% (10/205)	395	6.3% (25/395)
Low serum albumin^	354	Low (≤5/354)	205	Low (≤5/205)	396	Low (≤5/396)
Abnormal TSH^	353	3.1% (11/353)	205	Low (≤5/205)	393	3.8% (15/393)
Hypothyroidism (high TSH and low/normal free T4)^	352	1.7% (6/352)	205	Low (≤5/205)	393	1.8% (7/393)
Hyperthyroidism (low TSH and high/normal free T3/T4)^	352	Low (≤5/352)	205	Low (≤5/205)	393	2.0% (8/393)

^ Reference intervals vary by sex and/or age.

Table A6-2. Summary of lipid concentrations and liver, kidney and thyroid function biomarker concentrations for residents and workers of PFAS Management Areas, 2016–2020.

	Katherine, NT						Oakey, Qld						Williamtown, NSW					
	N	Mean	SD	P25	Med	P75	N	Mean	SD	P25	Med	P75	N	Mean	SD	P25	Med	P75
Total cholesterol (mmol/L)	354	5.1	1.0	4.4	5.1	5.8	205	5.1	1.2	4.2	5.0	5.8	396	5.1	1.3	4.4	5.1	5.8
HDL cholesterol (mmol/L)	354	1.4	0.4	1.1	1.3	1.6	205	1.3	0.3	1.1	1.3	1.5	396	1.4	0.4	1.1	1.3	1.6
LDL cholesterol (mmol/L)	335	3.0	0.9	2.4	2.9	3.6	205	3.0	0.9	2.3	3.0	3.6	389	3.0	1.0	2.4	3.0	3.6
Total:HDL cholesterol ratio	354	3.9	1.3	3.1	3.7	4.5	205	4.0	1.2	3.2	3.8	4.6	396	3.9	1.2	3.1	3.7	4.6
Triglycerides (mmol/L)	353	1.9	1.1	1.2	1.6	2.2	205	2.1	1.2	1.2	1.8	2.7	396	2.0	1.5	1.2	1.7	2.4
Serum creatinine (umol/L)	354	73.3	16.2	62.0	73.0	82.6	205	81.5	17.4	69.9	81.1	91.7	396	77.4	15.9	67.5	76.2	86.5
Urate (uric acid) (mmol/L)	354	0.3	0.1	0.3	0.3	0.4	205	0.3	0.1	0.3	0.3	0.4	396	0.3	0.1	0.3	0.3	0.4
eGFR (mL/min/1.73 m2) CKD-EPI formula	350	94.2	15.0	84.4	94.9	105.0	204	87.7	15.9	78.2	88.3	99.3	393	91.3	15.3	81.2	91.2	100.9
ALT (U/L)	322	16.7	10.8	10.1	13.2	20.0	203	19.0	10.6	11.4	16.0	25.2	388	18.1	10.8	10.8	15.3	22.3
AST (U/L)	351	17.1	13.9	11.3	15.1	19.7	205	20.7	9.3	14.0	18.8	24.4	395	18.8	7.9	13.7	17.4	21.7
GGT (U/L)	354	31.1	55.3	15.1	21.6	33.3	205	32.8	23.7	17.1	24.6	39.3	396	31.6	25.2	16.7	23.9	37.5
ALP (U/L)	354	76.1	27.3	60.7	73.7	87.1	205	75.4	20.4	62.3	72.1	86.2	395	75.9	21.2	61.3	73.2	87.8
Serum albumin (g/L)	354	42.3	3.3	40.3	42.5	44.8	205	42.7	2.5	41.0	42.8	44.7	396	42.8	2.9	40.9	42.9	44.8
Total protein (g/L)	354	71.0	5.0	68.0	70.8	74.2	205	70.8	4.2	68.4	70.6	73.4	396	71.4	5.1	68.3	71.3	74.0
TSH (mIU/L)	353	1.5	0.8	0.9	1.3	1.9	205	1.5	0.8	0.9	1.4	1.9	393	1.5	0.8	0.9	1.3	1.9
Free T3 (pmol/L)	354	4.3	0.7	3.9	4.3	4.6	205	4.3	0.5	4.0	4.4	4.7	394	4.3	0.6	3.9	4.3	4.7
Free T4 (pmol/L)	353	12.0	1.4	11.2	11.9	12.8	205	11.9	1.2	11.0	11.8	12.6	394	12.1	1.4	11.2	12.0	12.9

N: sample size; SD: standard deviation; P25: 25th percentile; Med: median; P75: 75th percentile.

Biochemical marker sensitivity analysis 1: adjustment for additional potential confounders that arise if kidney function is assumed to affect PFAS serum concentrations, including eGFR, smoking status and alcohol consumption

Table A6-3. Adjusted prevalence ratios of adverse lipid, liver, kidney and thyroid function biomarker concentrations per doubling in PFAS serum concentrations for residents and workers of PFAS Management Areas, 2016–2020. Sensitivity analysis: adjusting for additional potential confounders that arise if kidney function is assumed to affect PFAS serum concentrations.

	Katherine, NT		Oakey, Qld		Williamtown, NSW	
	N (cases) Exposed	PR‡ (95% CI)	N (cases) Exposed	PR‡ (95% CI)	N (cases) Exposed	PR‡ (95% CI)
High total cholesterol (>5.5 mmol/L)						
PFOS (total)	240 (87)	1.07 (0.96,1.18)	146 (47)	1.09 (0.95,1.25)	267 (98)	1.14 (1.03,1.26)
PFOS (branched isomers)	240 (87)	1.05 (0.93,1.19)	143 (47)	1.07 (0.87,1.32)	247 (88)	1.20 (1.06,1.35)
PFOA	240 (87)	1.22 (1.01,1.48)	146 (47)	1.06 (0.79,1.41)	267 (98)	1.30 (1.10,1.53)
PFHxS	240 (87)	1.02 (0.93,1.11)	146 (47)	1.09 (0.95,1.24)	267 (98)	1.16 (1.05,1.27)
Low HDL cholesterol^						
PFOS (total)	240 (31)	0.85 (0.68,1.08)	146 (13)	0.79 (0.54,1.16)	267 (25)	0.87 (0.68,1.12)#
PFOS (branched isomers)	240 (31)	0.94 (0.74,1.21)	143 (12)	0.79 (0.53,1.18)	247 (24)	1.14 (0.88,1.46)
PFOA	240 (31)	0.92 (0.60,1.39)	146 (13)	0.98 (0.61,1.56)	267 (25)	1.01 (0.64,1.58)#
PFHxS	240 (31)	0.85 (0.73,1.00)	146 (13)	0.96 (0.74,1.26)	267 (25)	0.96 (0.82,1.13)#
High LDL cholesterol (>4 mmol/L)						
PFOS (total)	225 (35)	1.01 (0.80,1.27)	146 (18)	0.98 (0.78,1.25)	262 (39)	1.06 (0.89,1.26)
PFOS (branched isomers)	225 (35)	0.96 (0.73,1.25)	143 (18)	1.06 (0.80,1.40)	242 (33)	1.12 (0.92,1.36)
PFOA	225 (35)	1.08 (0.71,1.64)	146 (18)	0.86 (0.58,1.29)#	262 (39)	1.34 (1.03,1.75)
PFHxS	225 (35)	0.96 (0.79,1.16)	146 (18)	1.01 (0.84,1.20)	262 (39)	1.11 (0.94,1.31)
High total:HDL cholesterol ratio (>4.5)						
PFOS (total)	240 (64)	0.91 (0.79,1.04)	146 (47)	1.07 (0.90,1.28)	267 (77)	1.02 (0.90,1.16)
PFOS (branched isomers)	240 (64)	0.99 (0.85,1.15)	143 (46)	1.18 (0.94,1.47)	247 (74)	1.06 (0.93,1.22)
PFOA	240 (64)	1.12 (0.85,1.46)	146 (47)	1.01 (0.80,1.27)	267 (77)	1.28 (1.01,1.63)
PFHxS	240 (64)	0.94 (0.84,1.05)	146 (47)	1.02 (0.89,1.16)	267 (77)	1.07 (0.96,1.19)
High triglycerides (>2 mmol/L)						
PFOS (total)	240 (82)	0.91 (0.79,1.04)	146 (62)	1.00 (0.86,1.16)	267 (91)	1.01 (0.88,1.14)
PFOS (branched isomers)	240 (82)	0.94 (0.81,1.09)	143 (60)	1.03 (0.86,1.24)	247 (89)	1.04 (0.90,1.21)
PFOA	240 (82)	1.11 (0.89,1.38)	146 (62)	1.10 (0.89,1.38)	267 (91)	1.17 (0.95,1.44)
PFHxS	240 (82)	0.92 (0.83,1.02)	146 (62)	1.03 (0.91,1.16)	267 (91)	1.03 (0.93,1.14)
High serum creatinine^						
PFOS (total)		NA		NA		NA
PFOS (branched isomers)		NA		NA		NA
PFOA		NA		NA		NA
PFHxS		NA		NA		NA

	Katherine, NT		Oakey, Qld		Williamtown, NSW	
	N (cases) Exposed	PR‡ (95% CI)	N (cases) Exposed	PR‡ (95% CI)	N (cases) Exposed	PR‡ (95% CI)
High urate (uric acid)^						
PFOS (total)	240 (17)	1.22 (0.94,1.59)	146 (8)	1.27 (0.97,1.65)	267 (20)	1.29 (0.95,1.74)
PFOS (branched isomers)	240 (17)	1.23 (0.92,1.65)	143 (7)	1.00 (0.65,1.53)	247 (18)	1.40 (1.02,1.92)#
PFOA	240 (17)	2.19 (1.24,3.85)	146 (8)	1.20 (0.64,2.25)	267 (20)	1.79 (1.11,2.89)
PFHxS	240 (17)	1.04 (0.81,1.34)	146 (8)	0.96 (0.73,1.26)	267 (20)	1.06 (0.80,1.41)
Low eGFR (<60 mL/min/1.73 m2) CKD-EPI formula						
PFOS (total)		NA		NA		NA
PFOS (branched isomers)		NA		NA		NA
PFOA		NA		NA		NA
PFHxS		NA		NA		NA
High ALT^						
PFOS (total)	219 (12)	0.94 (0.59,1.49)	145 (10)	NC	264 (12)	1.59 (1.11,2.27)
PFOS (branched isomers)	219 (12)	0.90 (0.55,1.48)	142 (9)	NC	244 (12)	1.59 (1.06,2.39)
PFOA	219 (12)	0.86 (0.53,1.38)	145 (10)	NC	264 (12)	1.19 (0.64,2.21)
PFHxS	219 (12)	0.91 (0.68,1.23)	145 (10)	NC	264 (12)	1.28 (0.81,2.01)
High AST^						
PFOS (total)	239 (10)	0.97 (0.61,1.56)	146 (8)	1.41 (0.86,2.30)	266 (4)	0.62 (0.40,0.95)
PFOS (branched isomers)	239 (10)	0.90 (0.51,1.59)	143 (6)	1.28 (0.49,3.30)	246 (4)	0.53 (0.23,1.24)
PFOA	239 (10)	0.87 (0.48,1.59)	146 (8)	1.42 (0.90,2.25)	266 (4)	0.86 (0.19,3.88)
PFHxS	239 (10)	0.95 (0.65,1.40)	146 (8)	1.27 (0.85,1.91)	266 (4)	0.56 (0.36,0.88)
High GGT^						
PFOS (total)	240 (32)	0.99 (0.82,1.20)	146 (25)	1.09 (0.84,1.40)	267 (43)	1.18 (0.97,1.44)
PFOS (branched isomers)	240 (32)	0.98 (0.78,1.22)	143 (24)	1.18 (0.82,1.70)	247 (41)	1.24 (0.99,1.56)
PFOA	240 (32)	1.09 (0.79,1.50)	146 (25)	1.26 (0.79,2.02)	267 (43)	1.32 (0.92,1.88)
PFHxS	240 (32)	0.97 (0.84,1.11)	146 (25)	0.99 (0.78,1.24)	267 (43)	1.17 (1.00,1.36)
High ALP^						
PFOS (total)	240 (10)	NC	146 (7)	1.06 (0.56,1.98)	266 (17)	1.20 (0.93,1.56)
PFOS (branched isomers)	240 (10)	NC	143 (7)	1.44 (0.73,2.86)	246 (15)	1.37 (1.00,1.87)
PFOA	240 (10)	NC	146 (7)	0.73 (0.46,1.15)	266 (17)	1.57 (0.80,3.08)
PFHxS	240 (10)	NC	146 (7)	1.12 (0.70,1.82)	266 (17)	0.98 (0.73,1.31)
Abnormal TSH^						
PFOS (total)		NA		NA		NA
PFOS (branched isomers)		NA		NA		NA
PFOA		NA		NA		NA
PFHxS		NA		NA		NA

Effects are prevalence ratios per doubling in PFAS serum concentrations in exposed communities

N: sample size; PR: prevalence ratio; NC: convergence not achieved; NA: not applicable.

‡ Adjusted for age, sex, level of education, gross household annual income, smoking status, alcohol consumption and estimated glomerular filtration rate. Age was modelled using a restricted cubic spline with 3 knots, as was the estimated glomerular filtration rate in models of lipid biomarkers.

^ Reference intervals vary by sex and age.

Estimated assuming an independence (rather than exchangeable) within-cluster correlation structure and cluster-robust standard errors.

Table A6-4. Differences in mean lipid, liver, kidney and thyroid function biomarker concentrations per doubling in PFAS serum concentrations for residents and workers of PFAS Management Areas, 2016–2020. Sensitivity analysis: adjusting for additional potential confounders that arise if kidney function is assumed to affect PFAS serum concentrations.

	Katherine, NT		Oakey, Qld		Williamtown, NSW	
	N Exposed	Difference¶ (95% CI)	N Exposed	Difference¶ (95% CI)	N Exposed	Difference¶ (95% CI)
Total cholesterol (mmol/L)						
PFOS (total)	240	−0.00 (−0.09,0.09)	146	0.10 (−0.03,0.23)	267	0.10 (0.01,0.19)
PFOS (branched isomers)	240	−0.01 (−0.11,0.09)	143	0.03 (−0.17,0.23)	247	0.11 (0.01,0.21)
PFOA	240	0.13 (−0.01,0.26)	146	−0.00 (−0.27,0.26)	267	0.19 (0.05,0.33)
PFHxS	240	−0.02 (−0.10,0.06)	146	0.03 (−0.12,0.17)	267	0.11 (0.03,0.19)
HDL cholesterol (mmol/L)						
PFOS (total)	240	0.02 (−0.00,0.05)	146	0.00 (−0.04,0.04)	267	0.03 (−0.01,0.06)
PFOS (branched isomers)	240	0.01 (−0.03,0.04)	143	−0.02 (−0.06,0.02)	247	−0.00 (−0.04,0.03)
PFOA	240	0.02 (−0.03,0.07)	146	−0.00 (−0.05,0.04)	267	−0.01 (−0.06,0.04)
PFHxS	240	0.02 (−0.00,0.04)	146	0.00 (−0.02,0.03)	267	0.00 (−0.02,0.03)
LDL cholesterol (mmol/L)						
PFOS (total)	225	0.01 (−0.08,0.10)	146	0.11 (0.02,0.19)	262	0.06 (−0.01,0.14)
PFOS (branched isomers)	225	−0.00 (−0.10,0.10)	143	0.09 (−0.01,0.20)	242	0.07 (−0.02,0.16)
PFOA	225	0.11 (−0.02,0.25)	146	0.09 (−0.03,0.22)	262	0.13 (−0.00,0.25)
PFHxS	225	−0.03 (−0.10,0.05)	146	0.04 (−0.03,0.12)	262	0.08 (0.01,0.15)
Total:HDL cholesterol ratio						
PFOS (total)	240	−0.07 (−0.17,0.03)	146	0.07 (−0.08,0.22)	267	0.01 (−0.09,0.11)
PFOS (branched isomers)	240	−0.02 (−0.15,0.10)	143	0.07 (−0.12,0.27)	247	0.10 (−0.01,0.22)
PFOA	240	0.03 (−0.14,0.21)	146	−0.01 (−0.28,0.26)	267	0.23 (0.08,0.38)
PFHxS	240	−0.07 (−0.15,0.02)	146	0.02 (−0.13,0.18)	267	0.08 (−0.01,0.16)
Triglycerides (mmol/L)						
PFOS (total)	240	−0.08 (−0.19,0.02)	146	0.05 (−0.11,0.21)	267	0.01 (−0.10,0.12)
PFOS (branched isomers)	240	−0.06 (−0.18,0.06)	143	0.00 (−0.14,0.15)	247	0.04 (−0.08,0.16)
PFOA	240	0.04 (−0.11,0.19)	146	0.01 (−0.15,0.18)	267	0.14 (−0.01,0.29)
PFHxS	240	−0.07 (−0.14,0.01)	146	0.05 (−0.09,0.19)	267	0.03 (−0.05,0.11)
Serum creatinine (umol/L)						
PFOS (total)		NA		NA		NA
PFOS (branched isomers)		NA		NA		NA
PFOA		NA		NA		NA
PFHxS		NA		NA		NA
Urate (uric acid) (mmol/L)						
PFOS (total)	240	−0.00 (−0.01,0.01)	146	−0.00 (−0.01,0.01)	267	0.00 (−0.00,0.01)

	Katherine, NT		Oakey, Qld		Williamtown, NSW	
	N Exposed	Difference[¶] (95% CI)	N Exposed	Difference[¶] (95% CI)	N Exposed	Difference[¶] (95% CI)
PFOS (branched isomers)	240	−0.00 (−0.01,0.01)	143	−0.00 (−0.01,0.01)	247	0.01 (0.00,0.02)
PFOA	240	0.01 (0.00,0.02)	146	0.00 (−0.01,0.01)	267	0.02 (0.01,0.02)
PFHxS	240	−0.00 (−0.01,0.00)	146	−0.00 (−0.01,0.00)	267	0.00 (−0.00,0.01)
eGFR (mL/min/1.73 m2) CKD-EPI formula						
PFOS (total)		NA		NA		NA
PFOS (branched isomers)		NA		NA		NA
PFOA		NA		NA		NA
PFHxS		NA		NA		NA
ALT (U/L)						
PFOS (total)	219	−0.87 (−1.89,0.14)	145	0.52 (−0.82,1.87)	264	0.34 (−0.51,1.18)
PFOS (branched isomers)	219	−0.87 (−2.07,0.33)	142	0.79 (−0.88,2.45)	244	0.92 (−0.16,2.00)
PFOA	219	−0.34 (−1.59,0.91)	145	0.68 (−0.70,2.06)	264	0.57 (−0.63,1.77)
PFHxS	219	−0.79 (−1.57,−0.01)	145	0.18 (−0.82,1.18)	264	0.38 (−0.33,1.10)
AST (U/L)						
PFOS (total)	239	−0.61 (−1.58,0.35)	146	0.70 (−0.67,2.06)	266	0.11 (−0.43,0.66)
PFOS (branched isomers)	239	−0.55 (−1.78,0.69)	143	0.34 (−0.86,1.54)	246	0.29 (−0.41,0.99)
PFOA	239	−0.20 (−1.30,0.91)	146	1.62 (0.60,2.63)	266	0.81 (−0.09,1.71)
PFHxS	239	−0.63 (−1.33,0.07)	146	0.51 (−0.51,1.53)	266	−0.14 (−0.66,0.38)
GGT (U/L)						
PFOS (total)	240	1.78 (−1.66,5.23)	146	0.57 (−2.15,3.28)	267	1.24 (−1.21,3.68)
PFOS (branched isomers)	240	1.73 (−2.65,6.11)	143	1.02 (−2.52,4.56)	247	1.71 (−0.93,4.35)
PFOA	240	1.57 (−1.66,4.80)	146	0.75 (−1.95,3.46)	267	1.47 (−1.43,4.36)
PFHxS	240	1.21 (−1.00,3.43)	146	0.25 (−1.97,2.46)	267	0.76 (−1.04,2.56)
ALP (U/L)						
PFOS (total)	240	0.00 (−2.05,2.05)	146	−0.75 (−2.63,1.14)	266	−1.53 (−3.23,0.18)
PFOS (branched isomers)	240	−0.45 (−2.71,1.82)	143	0.82 (−1.62,3.25)	246	0.51 (−1.64,2.65)
PFOA	240	2.10 (−0.63,4.83)	146	−0.65 (−3.05,1.76)	266	2.10 (−0.82,5.02)
PFHxS	240	−0.33 (−2.04,1.38)	146	0.24 (−1.44,1.91)	266	−1.00 (−2.51,0.52)
Serum albumin (g/L)						
PFOS (total)	240	−0.02 (−0.28,0.25)	146	0.45 (0.14,0.76)	267	0.09 (−0.14,0.32)
PFOS (branched isomers)	240	−0.05 (−0.34,0.24)	143	0.45 (0.07,0.83)	247	0.16 (−0.12,0.44)
PFOA	240	0.12 (−0.30,0.53)	146	0.52 (0.09,0.94)	267	0.31 (−0.07,0.69)
PFHxS	240	−0.09 (−0.30,0.12)	146	0.22 (−0.02,0.45)	267	0.08 (−0.13,0.30)
Total protein (g/L)						
PFOS (total)	240	−0.03 (−0.41,0.35)	146	0.66 (0.11,1.21)	267	−0.05 (−0.43,0.33)
PFOS (branched isomers)	240	−0.03 (−0.47,0.41)	143	0.43 (−0.18,1.04)	247	0.12 (−0.36,0.59)

	Katherine, NT		Oakey, Qld		Williamtown, NSW	
	N Exposed	Difference¶ (95% CI)	N Exposed	Difference¶ (95% CI)	N Exposed	Difference¶ (95% CI)
PFOA	240	0.27 (−0.28,0.81)	146	0.53 (−0.11,1.18)	267	0.50 (−0.05,1.05)
PFHxS	240	−0.17 (−0.50,0.16)	146	0.35 (−0.07,0.77)	267	0.08 (−0.27,0.43)
TSH (mIU/L)						
PFOS (total)		NA		NA		NA
PFOS (branched isomers)		NA		NA		NA
PFOA		NA		NA		NA
PFHxS		NA		NA		NA
Free T3 (pmol/L)						
PFOS (total)		NA		NA		NA
PFOS (branched isomers)		NA		NA		NA
PFOA		NA		NA		NA
PFHxS		NA		NA		NA
Free T4 (pmol/L)						
PFOS (total)		NA		NA		NA
PFOS (branched isomers)		NA		NA		NA
PFOA		NA		NA		NA
PFHxS		NA		NA		NA

N: sample size; NC: convergence not achieved; NA: not applicable.

¶ Adjusted for age, sex, level of education, gross household annual income, smoking status, alcohol consumption and estimated glomerular filtration rate. Age was modelled using a restricted cubic spline with 3 knots, as was the estimated glomerular filtration rate in models of lipid biomarkers.

Estimated assuming an independence (rather than exchangeable) within-cluster correlation structure and cluster-robust standard errors.

Biochemical marker sensitivity analysis 2: exclusion of exposed participants who now live in comparison communities

Table A6-5. Adjusted prevalence ratios of adverse lipid, liver, kidney and thyroid function biomarker concentrations per doubling in PFAS serum concentrations for residents and workers of PFAS Management Areas, 2016–2020. Sensitivity analysis: excluding exposed participants who now live in comparison communities.

	Katherine, NT		Oakey, Qld		Williamtown, NSW	
	N (cases) Exposed	PR‡ (95% CI)	N (cases) Exposed	PR‡ (95% CI)	N (cases) Exposed	PR‡ (95% CI)
High total cholesterol (>5.5 mmol/L)						
PFOS (total)	238 (87)	1.04 (0.94,1.16)	121 (40)	1.04 (0.89,1.21)	268 (95)	1.15 (1.03,1.27)
PFOS (branched isomers)	238 (87)	1.02 (0.89,1.16)	118 (40)	1.00 (0.81,1.23)	246 (85)	1.20 (1.07,1.36)
PFOA	238 (87)	1.13 (0.92,1.39)	121 (40)	1.08 (0.80,1.46)	268 (95)	1.31 (1.10,1.57)
PFHxS	238 (87)	0.99 (0.90,1.08)	121 (40)	1.01 (0.88,1.16)	268 (95)	1.18 (1.07,1.30)
Low HDL cholesterol^						
PFOS (total)	238 (29)	0.92 (0.69,1.23)	121 (9)	0.96 (0.55,1.65)	268 (25)	0.89 (0.63,1.24)
PFOS (branched isomers)	238 (29)	0.99 (0.75,1.32)	118 (8)	0.96 (0.54,1.69)	246 (24)	1.16 (0.81,1.66)
PFOA	238 (29)	0.85 (0.55,1.34)	121 (9)	0.78 (0.45,1.37)	268 (25)	1.00 (0.63,1.58)
PFHxS	238 (29)	0.92 (0.78,1.08)	121 (9)	1.01 (0.68,1.51)	268 (25)	0.97 (0.80,1.19)
High LDL cholesterol (>4 mmol/L)						
PFOS (total)	222 (34)	0.98 (0.76,1.26)	121 (11)	1.02 (0.80,1.30)	263 (38)	1.05 (0.88,1.25)
PFOS (branched isomers)	222 (34)	0.93 (0.70,1.23)	118 (11)	1.06 (0.78,1.45)	241 (32)	1.09 (0.90,1.34)
PFOA	222 (34)	1.09 (0.69,1.71)	121 (11)	0.93 (0.61,1.43)	263 (38)	1.35 (1.01,1.79)
PFHxS	222 (34)	0.93 (0.75,1.14)	121 (11)	1.03 (0.81,1.31)	263 (38)	1.12 (0.96,1.32)
High total:HDL cholesterol ratio (>4.5)						
PFOS (total)	238 (64)	0.93 (0.81,1.07)	121 (37)	1.08 (0.90,1.30)	268 (76)	1.02 (0.90,1.15)
PFOS (branched isomers)	238 (64)	1.02 (0.87,1.20)	118 (36)	1.15 (0.93,1.43)	246 (73)	1.08 (0.94,1.23)
PFOA	238 (64)	1.03 (0.78,1.35)	121 (37)	0.96 (0.72,1.28)	268 (76)	1.27 (1.01,1.61)
PFHxS	238 (64)	0.96(0.85,1.07)	121 (37)	1.00 (0.86,1.16)	268 (76)	1.07 (0.96,1.19)
High triglycerides (>2 mmol/L)						
PFOS (total)	238 (82)	0.91 (0.79,1.05)	121 (56)	0.96 (0.82,1.13)	268 (89)	1.00 (0.88,1.14)
PFOS (branched isomers)	238 (82)	0.95 (0.82,1.10)	118 (54)	1.02 (0.85,1.21)	246 (87)	1.05 (0.91,1.21)
PFOA	238 (82)	1.10 (0.89,1.38)	121 (56)	0.97 (0.78,1.19)	268 (89)	1.16 (0.94,1.42)
PFHxS	238 (82)	0.93 (0.83,1.04)	121 (56)	0.97 (0.87,1.09)	268 (89)	1.03 (0.93,1.15)
High serum creatinine^						
PFOS (total)	238 (6)	1.00 (0.68,1.46)	121 (11)	0.94 (0.51,1.73)	268 (6)	1.22 (0.85,1.75)
PFOS (branched isomers)	238 (6)	1.06 (0.71,1.59)	118 (10)	0.89 (0.40,1.99)	246 (4)	1.15 (0.72,1.85)
PFOA	238 (6)	0.69 (0.22,2.24)	121 (11)	0.85 (0.32,2.23)	268 (6)	1.78 (1.32,2.41)
PFHxS	238 (6)	0.87 (0.63,1.19)	121 (11)	1.01 (0.61,1.68)	268 (6)	1.18 (0.83,1.68)

	Katherine, NT		Oakey, Qld		Williamtown, NSW	
	N (cases) Exposed	PR‡ (95% CI)	N (cases) Exposed	PR‡ (95% CI)	N (cases) Exposed	PR‡ (95% CI)
High urate (uric acid)^						
PFOS (total)	238 (18)	1.17 (0.95,1.43)	121 (9)	1.20 (0.81,1.78)	268 (20)	1.32 (1.04,1.66)
PFOS (branched isomers)	238 (18)	1.16 (0.92,1.47)	118 (8)	0.82 (0.45,1.48)	246 (17)	1.52 (1.18,1.96)#
PFOA	238 (18)	1.58 (0.86,2.91)	121 (9)	1.04 (0.35,3.10)	268 (20)	2.21 (1.30,3.75)
PFHxS	238 (18)	1.01 (0.83,1.23)	121 (9)	0.95 (0.58,1.56)	268 (20)	1.20 (0.94,1.52)
Low eGFR (<60 mL/min/1.73 m2) CKD-EPI formula						
PFOS (total)	237 (4)	NC	121 (8)	0.93 (0.45,1.90)	266 (7)	1.17 (0.83,1.66)
PFOS (branched isomers)	237 (4)	NC	118 (8)	1.11 (0.41,3.01)	245 (5)	0.81 (0.63,1.04)
PFOA	237 (4)	NC	121 (8)	1.10 (0.27,4.42)	266 (7)	1.19 (0.72,1.94)
PFHxS	237 (4)	NC	121 (8)	1.01 (0.55,1.86)	266 (7)	1.05 (0.71,1.54)
High ALT^						
PFOS (total)	215 (12)	0.91 (0.55,1.50)	120 (8)	NC	265 (11)	1.55 (1.11,2.19)
PFOS (branched isomers)	215 (12)	0.90 (0.52,1.58)	117 (7)	NC	243 (11)	1.70 (1.15,2.53)
PFOA	215 (12)	0.79 (0.51,1.23)	120 (8)	NC	265 (11)	1.14 (0.67,1.95)
PFHxS	215 (12)	0.89 (0.64,1.24)	120 (8)	NC	265 (11)	1.36 (0.97,1.91)
High AST^						
PFOS (total)	237 (8)	1.00 (0.67,1.51)	121 (6)	1.31 (0.78,2.22)	267 (3)	NC
PFOS (branched isomers)	237 (8)	0.98 (0.56,1.69)	118 (4)	0.98 (0.31,3.11)	245 (3)	NC
PFOA	237 (8)	0.85 (0.53,1.37)	121 (6)	1.33 (0.53,3.32)	267 (3)	NC
PFHxS	237 (8)	1.04 (0.73,1.47)	121 (6)	1.19 (0.76,1.87)	267 (3)	NC
High GGT^						
PFOS (total)	238 (31)	0.93 (0.76,1.13)	121 (19)	1.08 (0.79,1.48)	268 (44)	1.13 (0.91,1.39)
PFOS (branched isomers)	238 (31)	0.90 (0.71,1.15)	118 (18)	1.12 (0.74,1.70)	246 (42)	1.16 (0.91,1.48)
PFOA	238 (31)	1.04 (0.76,1.43)	121 (19)	1.14 (0.61,2.13)	268 (44)	1.32 (0.94,1.85)
PFHxS	238 (31)	0.93 (0.81,1.08)	121 (19)	0.93 (0.72,1.21)	268 (44)	1.11 (0.95,1.31)
High ALP^						
PFOS (total)	238 (10)	NC	121 (7)	0.85 (0.49,1.47)	267 (17)	1.18 (0.92,1.51)
PFOS (branched isomers)	238 (10)	NC	118 (7)	1.13 (0.61,2.09)	245 (15)	1.37 (1.03,1.83)
PFOA	238 (10)	NC	121 (7)	0.77 (0.55,1.06)	267 (17)	1.47 (0.79,2.74)
PFHxS	238 (10)	NC	121 (7)	1.05 (0.70,1.56)	267 (17)	0.95 (0.71,1.27)
Abnormal TSH^						
PFOS (total)	238 (8)	NC	121 (1)	0.20 (0.07,0.59)	267 (10)	1.22 (0.89,1.68)
PFOS (branched isomers)	238 (8)	NC	118 (1)	0.31 (0.19,0.49)	245 (7)	NC
PFOA	238 (8)	NC	121 (1)	0.73 (0.53,1.00)	267 (10)	0.84 (0.47,1.52)
PFHxS	238 (8)	NC	121 (1)	0.52 (0.36,0.74)	267 (10)	1.24 (0.91,1.68)

Effects are prevalence ratios per doubling in PFAS serum concentrations in exposed communities
N: sample size; PR: prevalence ratio; NC: convergence not achieved.
‡ Adjusted for age, sex, level of education and gross household annual income. Age was modelled using a restricted cubic spline with 3 knots.
^ Reference intervals vary by sex and age.
# Estimated assuming an independence (rather than exchangeable) within-cluster correlation structure and cluster-robust standard errors.

Table A6-6. Differences in mean lipid, liver, kidney and thyroid function biomarker concentrations per doubling in PFAS serum concentrations for residents and workers of PFAS Management Areas, 2016–2020. Sensitivity analysis: excluding exposed participants who now live in comparison communities.

	Katherine, NT		Oakey, Qld		Williamtown, NSW	
	N Exposed	Difference[¶] (95% CI)	N Exposed	Difference[¶] (95% CI)	N Exposed	Difference[¶] (95% CI)
Total cholesterol (mmol/L)						
PFOS (total)	238	−0.02 (−0.11,0.08)	121	0.06 (−0.08,0.19)	268	0.11 (0.02,0.20)
PFOS (branched isomers)	238	−0.03 (−0.14,0.07)	118	−0.04 (−0.26,0.18)	246	0.10 (−0.00,0.21)
PFOA	238	0.12 (−0.03,0.26)	121	−0.04 (−0.40,0.32)	268	0.21 (0.08,0.35)
PFHxS	238	−0.03 (−0.12,0.05)	121	−0.02 (−0.19,0.14)	268	0.10 (0.02,0.19)
HDL cholesterol (mmol/L)						
PFOS (total)	238	0.02 (−0.02,0.05)	121	−0.01 (−0.05,0.03)	268	0.03 (−0.01,0.07)
PFOS (branched isomers)	238	−0.00 (−0.04,0.03)	118	−0.03 (−0.07,0.01)	246	−0.01 (−0.04,0.03)
PFOA	238	0.03 (−0.02,0.08)	121	0.01 (−0.04,0.06)	268	−0.00 (−0.06,0.05)
PFHxS	238	0.02 (−0.01,0.04)	121	0.00 (−0.03,0.03)	268	0.01 (−0.02,0.04)
LDL cholesterol (mmol/L)						
PFOS (total)	222	0.01 (−0.08,0.11)	121	0.07 (−0.02,0.16)	263	0.07 (−0.01,0.14)
PFOS (branched isomers)	222	−0.01 (−0.11,0.09)	118	0.03 (−0.08,0.15)	241	0.06 (−0.03,0.16)
PFOA	222	0.12 (−0.02,0.27)	121	0.09 (−0.05,0.22)	263	0.15 (0.03,0.27)
PFHxS	222	−0.03 (−0.11,0.05)	121	0.01 (−0.07,0.09)	263	0.09 (0.02,0.15)
Total:HDL cholesterol ratio						
PFOS (total)	238	−0.06 (−0.16,0.05)	121	0.10 (−0.06,0.26)	268	0.01 (−0.09,0.11)
PFOS (branched isomers)	238	−0.01 (−0.14,0.11)	118	0.06 (−0.17,0.30)	246	0.10 (−0.01,0.22)
PFOA	238	0.00 (−0.19,0.20)	121	−0.09 (−0.48,0.30)	268	0.23 (0.08,0.38)
PFHxS	238	−0.06 (−0.15,0.02)	121	−0.01 (−0.19,0.17)	268	0.07 (−0.02,0.15)
Triglycerides (mmol/L)						
PFOS (total)	238	−0.09 (−0.19,0.02)	121	0.05 (−0.12,0.21)	268	0.01 (−0.10,0.11)
PFOS (branched isomers)	238	−0.06 (−0.18,0.06)	118	0.00 (−0.15,0.15)	246	0.05 (−0.07,0.17)
PFOA	238	0.03 (−0.13,0.18)	121	−0.08 (−0.30,0.15)	268	0.14 (−0.00,0.28)
PFHxS	238	−0.06 (−0.14,0.02)	121	0.02 (−0.13,0.16)	268	0.03 (−0.06,0.11)
Serum creatinine (umol/L)						
PFOS (total)	238	0.35 (−1.02,1.73)	121	0.24 (−2.42,2.89)	268	0.34 (−0.68,1.36)
PFOS (branched isomers)	238	0.57 (−0.80,1.94)	118	−0.77 (−4.78,3.25)	246	0.15 (−1.14,1.44)
PFOA	238	−1.41 (−5.25,2.43)	121	−0.97 (−6.73,4.80)	268	−0.28 (−1.90,1.33)
PFHxS	238	−0.71 (−1.57,0.14)	121	−0.10 (−3.00,2.79)	268	0.00 (−0.98,0.99)
Urate (uric acid) (mmol/L)						
PFOS (total)	238	−0.00 (−0.01,0.01)	121	0.00 (−0.01,0.01)	268	0.00 (−0.00,0.01)
PFOS (branched isomers)	238	0.00 (−0.01,0.01)	118	−0.01 (−0.02,0.01)	246	0.01 (0.00,0.02)

	Katherine, NT		Oakey, Qld		Williamtown, NSW	
	N Exposed	Difference¶ (95% CI)	N Exposed	Difference¶ (95% CI)	N Exposed	Difference¶ (95% CI)
PFOA	238	0.01 (−0.00,0.02)	121	0.01 (−0.01,0.03)	268	0.02 (0.01,0.03)
PFHxS	238	−0.00 (−0.01,0.00)	121	−0.00 (−0.01,0.01)	268	0.01 (0.00,0.01)
eGFR (mL/min/1.73 m2) CKD-EPI formula						
PFOS (total)	237	−0.32 (−1.51,0.87)	121	−0.85 (−3.05,1.36)	266	−0.23 (−1.20,0.73)
PFOS (branched isomers)	237	−0.64 (−1.95,0.67)	118	−0.20 (−3.22,2.82)	245	−0.18 (−1.38,1.03)
PFOA	237	0.36 (−2.43,3.14)	121	0.07 (−4.07,4.21)	266	0.32 (−1.30,1.94)
PFHxS	237	0.60 (−0.24,1.45)	121	−0.49 (−2.67,1.70)	266	0.02 (−0.91,0.94)
ALT (U/L)						
PFOS (total)	215	−0.89 (−1.94,0.16)	120	0.04 (−1.52,1.60)	265	0.38 (−0.46,1.21)
PFOS (branched isomers)	215	−0.85 (−2.07,0.36)	117	0.10 (−1.75,1.96)	243	1.12 (0.10,2.13)
PFOA	215	−0.52 (−1.82,0.77)	120	0.25 (−1.43,1.93)	265	0.57 (−0.60,1.74)
PFHxS	215	−0.86 (−1.70,−0.01)	120	−0.27 (−1.39,0.85)	265	0.45 (−0.21,1.11)
AST (U/L)						
PFOS (total)	237	−0.58 (−1.56,0.40)	121	0.94 (−0.59,2.47)	267	0.22 (−0.29,0.74)
PFOS (branched isomers)	237	−0.46 (−1.62,0.70)	118	0.37 (−0.88,1.62)	245	0.48 (−0.14,1.10)
PFOA	237	−0.04 (−1.09,1.00)	121	1.44 (0.26,2.62)	267	0.72 (−0.16,1.61)
PFHxS	237	−0.52 (−1.25,0.21)	121	0.62 (−0.45,1.70)	267	0.04 (−0.42,0.50)
GGT (U/L)						
PFOS (total)	238	1.25 (−2.33,4.83)	121	0.73 (−2.34,3.81)	268	1.03 (−1.35,3.40)
PFOS (branched isomers)	238	0.80 (−3.23,4.83)	118	0.74 (−3.00,4.48)	246	1.27 (−1.32,3.87)
PFOA	238	0.62 (−3.05,4.30)	121	0.06 (−3.02,3.15)	268	0.97 (−1.55,3.49)
PFHxS	238	1.26 (−1.17,3.70)	121	−0.29 (−2.58,2.00)	268	0.72 (−0.99,2.42)
ALP (U/L)						
PFOS (total)	238	−0.03 (−2.25,2.19)	121	−0.90 (−3.29,1.49)	267	−1.07 (−2.83,0.70)
PFOS (branched isomers)	238	−0.20 (−2.61,2.21)	118	1.11 (−1.54,3.76)	245	0.93 (−1.19,3.04)
PFOA	238	1.77 (−1.14,4.68)	121	−2.23 (−4.96,0.49)	267	1.43 (−1.80,4.67)
PFHxS	238	−0.23 (−2.12,1.65)	121	0.26 (−1.57,2.09)	267	−0.99 (−2.75,0.76)
Serum albumin (g/L)						
PFOS (total)	238	−0.02 (−0.30,0.27)	121	0.22 (−0.13,0.58)	268	0.11 (−0.12,0.34)
PFOS (branched isomers)	238	−0.01 (−0.31,0.30)	118	0.19 (−0.22,0.61)	246	0.17 (−0.11,0.46)
PFOA	238	0.37 (−0.16,0.90)	121	0.24 (−0.28,0.76)	268	0.27 (−0.10,0.65)
PFHxS	238	−0.11 (−0.34,0.13)	121	0.09 (−0.18,0.36)	268	0.12 (−0.09,0.34)
Total protein (g/L)						
PFOS (total)	238	−0.02 (−0.42,0.38)	121	0.68 (0.04,1.32)	268	−0.08 (−0.46,0.30)
PFOS (branched isomers)	238	0.02 (−0.43,0.48)	118	0.40 (−0.28,1.08)	246	0.08 (−0.40,0.56)
PFOA	238	0.57 (−0.03,1.18)	121	0.39 (−0.52,1.29)	268	0.41 (−0.11,0.94)

	Katherine, NT		Oakey, Qld		Williamtown, NSW	
	N Exposed	Difference¶ (95% CI)	N Exposed	Difference¶ (95% CI)	N Exposed	Difference¶ (95% CI)
PFHxS	238	−0.18 (−0.53,0.16)	121	0.38 (−0.08,0.84)	268	0.04 (−0.34,0.41)
TSH (mIU/L)						
PFOS (total)	238	0.00 (−0.06,0.07)	121	0.01 (−0.10,0.11)	267	0.02 (−0.04,0.07)
PFOS (branched isomers)	238	0.01 (−0.07,0.08)	118	0.05 (−0.05,0.15)	245	0.02 (−0.06,0.09)
PFOA	238	0.10 (−0.01,0.22)	121	0.10 (−0.02,0.21)	267	0.04 (−0.06,0.14)
PFHxS	238	0.01 (−0.04,0.06)	121	0.02 (−0.05,0.09)	267	−0.01 (−0.06,0.04)
Free T3 (pmol/L)						
PFOS (total)	238	−0.01 (−0.05,0.03)	121	−0.01 (−0.08,0.06)	267	−0.01 (−0.05,0.03)
PFOS (branched isomers)	238	0.01 (−0.04,0.06)	118	−0.01 (−0.10,0.08)	245	0.04 (−0.02,0.09)
PFOA	238	0.01 (−0.05,0.08)	121	−0.09 (−0.17,−0.01)	267	−0.00 (−0.08,0.07)
PFHxS	238	−0.00 (−0.04,0.03)	121	−0.03 (−0.10,0.03)	267	−0.00 (−0.04,0.03)
Free T4 (pmol/L)						
PFOS (total)	237	0.01 (−0.09,0.12)	121	0.04 (−0.10,0.18)	267	−0.02 (−0.15,0.11)
PFOS (branched isomers)	237	0.05 (−0.07,0.17)	118	0.08 (−0.07,0.22)	245	0.02 (−0.13,0.17)
PFOA	237	0.06 (−0.11,0.24)	121	−0.06 (−0.21,0.10)	267	−0.02 (−0.23,0.19)
PFHxS	237	−0.01 (−0.10,0.08)	121	0.05 (−0.05,0.15)	267	0.07 (−0.05,0.18)

N: sample size; NC: convergence not achieved.

¶ Adjusted for age, sex, level of education and gross household annual income. Age was modelled using a restricted cubic spline with 3 knots.

Estimated assuming an independence (rather than exchangeable) within-cluster correlation structure and cluster-robust standard errors.

Biochemical marker sensitivity analysis 3: exclusion of exposed participants who have not lived in the exposed communities in the last 15 years

Table A6-7. Adjusted prevalence ratios of adverse lipid, liver, kidney and thyroid function biomarker concentrations per doubling in PFAS serum concentrations for residents and workers of PFAS Management Areas, 2016–2020. Sensitivity analysis: excluding exposed participants who have not lived in the exposed communities in the last 15 years.

	Katherine, NT		Oakey, Qld		Williamtown, NSW	
	N (cases) Exposed	PR‡ (95% CI)	N (cases) Exposed	PR‡ (95% CI)	N (cases) Exposed	PR‡ (95% CI)
High total cholesterol (>5.5 mmol/L)						
PFOS (total)	234 (85)	1.05 (0.94,1.18)	146 (46)	1.03 (0.89,1.20)	252 (89)	1.10 (0.98,1.23)
PFOS (branched isomers)	234 (85)	1.03 (0.90,1.18)	143 (46)	1.00 (0.82,1.21)	232 (80)	1.14 (1.00,1.30)
PFOA	234 (85)	1.18 (0.94,1.47)	146 (46)	1.00 (0.77,1.29)	252 (89)	1.28 (1.06,1.54)
PFHxS	234 (85)	1.02 (0.93,1.12)	146 (46)	1.03 (0.91,1.17)	252 (89)	1.15 (1.03,1.27)
Low HDL cholesterol^						
PFOS (total)	234 (30)	0.88 (0.67,1.16)	146 (13)	0.89 (0.57,1.39)	252 (25)	0.91 (0.61,1.35)
PFOS (branched isomers)	234 (30)	0.95 (0.71,1.26)	143 (12)	0.95 (0.60,1.49)	232 (24)	1.02 (0.75,1.39)#
PFOA	234 (30)	0.83 (0.54,1.29)	146 (13)	1.25 (0.74,2.11)	252 (25)	1.04 (0.63,1.72)
PFHxS	234 (30)	0.86 (0.72,1.02)	146 (13)	1.09 (0.83,1.44)	252 (25)	1.00 (0.80,1.24)
High LDL cholesterol (>4 mmol/L)						
PFOS (total)	218 (34)	0.97 (0.74,1.26)	146 (19)	1.02 (0.81,1.29)	247 (40)	1.02 (0.85,1.22)
PFOS (branched isomers)	218 (34)	0.93 (0.70,1.24)	143 (19)	1.06 (0.82,1.38)	227 (34)	1.05 (0.86,1.28)
PFOA	218 (34)	1.04 (0.64,1.67)	146 (19)	0.93 (0.67,1.30)	247 (40)	1.37 (1.04,1.81)
PFHxS	218 (34)	0.94 (0.76,1.16)	146 (19)	1.00 (0.85,1.19)	247 (40)	1.06 (0.90,1.25)
High total:HDL cholesterol ratio (>4.5)						
PFOS (total)	234 (65)	0.91 (0.79,1.04)	146 (47)	1.09 (0.91,1.29)	252 (75)	1.00 (0.88,1.14)
PFOS (branched isomers)	234 (65)	0.99 (0.84,1.16)	143 (46)	1.19 (0.98,1.45)	232 (72)	1.06 (0.93,1.22)
PFOA	234 (65)	0.97 (0.75,1.26)	146 (47)	1.04 (0.81,1.33)	252 (75)	1.26 (0.99,1.60)
PFHxS	234 (65)	0.92 (0.82,1.03)	146 (47)	1.03 (0.90,1.18)	252 (75)	1.05 (0.94,1.17)
High triglycerides (>2 mmol/L)						
PFOS (total)	234 (81)	0.92 (0.80,1.06)	146 (64)	1.05 (0.90,1.22)	252 (84)	0.99 (0.87,1.14)
PFOS (branched isomers)	234 (81)	0.95 (0.82,1.11)	143 (62)	1.10 (0.93,1.31)	232 (82)	1.03 (0.89,1.19)
PFOA	234 (81)	1.10 (0.88,1.38)	146 (64)	1.18 (0.96,1.46)	252 (84)	1.11 (0.89,1.37)
PFHxS	234 (81)	0.92 (0.82,1.03)	146 (64)	1.06 (0.95,1.19)	252 (84)	1.01 (0.91,1.12)
High serum creatinine^						
PFOS (total)	234 (8)	0.82 (0.56,1.20)	146 (11)	1.20 (0.71,2.03)	252 (7)	1.10 (0.74,1.64)
PFOS (branched isomers)	234 (8)	0.91 (0.63,1.30)	143 (10)	1.21 (0.56,2.62)	232 (5)	0.94 (0.53,1.68)
PFOA	234 (8)	0.83 (0.29,2.40)	146 (11)	1.57 (0.44,5.67)	252 (7)	1.78 (1.32,2.41)

	Katherine, NT		Oakey, Qld		Williamtown, NSW	
	N (cases) Exposed	PR‡ (95% CI)	N (cases) Exposed	PR‡ (95% CI)	N (cases) Exposed	PR‡ (95% CI)
PFHxS	234 (8)	0.84 (0.66,1.08)	146 (11)	1.22 (0.75,2.00)	252 (7)	0.96 (0.59,1.54)
High urate (uric acid)^						
PFOS (total)	234 (19)	1.15 (0.94,1.41)	146 (8)	1.34 (0.90,2.00)	252 (19)	1.15 (0.88,1.49)
PFOS (branched isomers)	234 (19)	1.15 (0.92,1.45)	143 (7)	0.83 (0.38,1.79)	232 (16)	1.24 (0.88,1.74)#
PFOA	234 (19)	1.67 (0.92,3.05)	146 (8)	1.00 (0.35,2.90)	252 (19)	1.76 (1.11,2.78)
PFHxS	234 (19)	0.97 (0.78,1.20)	146 (8)	0.99 (0.55,1.75)	252 (19)	0.97 (0.72,1.31)
Low eGFR (<60 mL/min/1.73 m2) CKD-EPI formula						
PFOS (total)	233 (7)	0.88 (0.59,1.32)	146 (9)	1.14 (0.63,2.05)	250 (9)	1.07 (0.76,1.52)
PFOS (branched isomers)	233 (7)	0.87 (0.55,1.39)	143 (9)	1.35 (0.55,3.29)	231 (7)	0.76 (0.52,1.09)
PFOA	233 (7)	0.66 (0.18,2.41)	146 (9)	1.54 (0.32,7.41)	250 (9)	1.25 (0.80,1.94)
PFHxS	233 (7)	0.88 (0.66,1.16)	146 (9)	1.14 (0.66,1.99)	250 (9)	0.96 (0.63,1.45)
High ALT^						
PFOS (total)	211 (11)	0.91 (0.54,1.53)	145 (10)	NC	249 (9)	NC
PFOS (branched isomers)	211 (11)	0.89 (0.49,1.61)	142 (9)	NC	229 (9)	NC
PFOA	211 (11)	0.74 (0.47,1.17)	145 (10)	NC	249 (9)	NC
PFHxS	211 (11)	0.90 (0.62,1.29)	145 (10)	NC	249 (9)	NC
High AST^						
PFOS (total)	233 (10)	0.86 (0.54,1.36)	146 (7)	1.28 (0.78,2.09)	251 (4)	NC
PFOS (branched isomers)	233 (10)	0.81 (0.45,1.45)	143 (5)	0.95 (0.47,1.89)	231 (4)	NC
PFOA	233 (10)	0.71 (0.43,1.17)	146 (7)	1.27 (0.83,1.96)	251 (4)	NC
PFHxS	233 (10)	0.88 (0.57,1.36)	146 (7)	1.21 (0.79,1.86)	251 (4)	NC
High GGT^						
PFOS (total)	234 (31)	0.93 (0.76,1.13)	146 (25)	1.07 (0.82,1.39)	252 (40)	1.05 (0.84,1.31)
PFOS (branched isomers)	234 (31)	0.90 (0.71,1.15)	143 (24)	1.14 (0.80,1.63)	232 (38)	1.05 (0.83,1.32)
PFOA	234 (31)	1.07 (0.78,1.46)	146 (25)	1.28 (0.80,2.04)	252 (40)	1.17 (0.84,1.63)
PFHxS	234 (31)	0.94 (0.81,1.09)	146 (25)	0.96 (0.76,1.20)	252 (40)	1.03 (0.88,1.20)
High ALP^						
PFOS (total)	234 (11)	NC	146 (9)	1.04 (0.67,1.63)	251 (15)	1.26 (0.97,1.64)
PFOS (branched isomers)	234 (11)	NC	143 (9)	1.27 (0.75,2.17)	231 (13)	1.45 (1.08,1.94)
PFOA	234 (11)	NC	146 (9)	0.91 (0.63,1.32)	251 (15)	1.82 (0.97,3.39)
PFHxS	234 (11)	NC	146 (9)	1.10 (0.78,1.54)	251 (15)	1.04 (0.78,1.39)
Abnormal TSH^						
PFOS (total)	234 (7)	1.16 (0.90,1.50)	146 (2)	0.41 (0.18,0.92)	251 (7)	1.45 (1.03,2.03)
PFOS (branched isomers)	234 (7)	1.14 (0.79,1.66)	143 (2)	0.39 (0.20,0.75)	231 (4)	NC
PFOA	234 (7)	1.45 (0.82,2.59)	146 (2)	4.51 (1.31,15.45)	251 (7)	0.92 (0.37,2.30)

	Katherine, NT		Oakey, Qld		Williamtown, NSW	
	N (cases) Exposed	PR‡ (95% CI)	N (cases) Exposed	PR‡ (95% CI)	N (cases) Exposed	PR‡ (95% CI)
PFHxS	234 (7)	0.98 (0.77,1.24)	146 (2)	0.56 (0.37,0.84)	251 (7)	1.22 (0.80,1.86)

N: sample size; PR: prevalence ratio; NC: convergence not achieved.

‡ Adjusted for age, sex, level of education and gross household annual income. Age was modelled using a restricted cubic spline with 3 knots.

^ Reference intervals vary by sex and age.

Estimated assuming an independence (rather than exchangeable) within-cluster correlation structure and cluster-robust standard errors.

Table A6-8. Differences in mean lipid, liver, kidney and thyroid function biomarker concentrations per doubling in PFAS serum concentrations for residents and workers of PFAS Management Areas, 2016–2020. Sensitivity analysis: excluding exposed participants who have not lived in the exposed communities in the last 15 years.

	Katherine, NT		Oakey, Qld		Williamtown, NSW	
	N Exposed	Difference[¶] (95% CI)	N Exposed	Difference[¶] (95% CI)	N Exposed	Difference[¶] (95% CI)
Total cholesterol (mmol/L)						
PFOS (total)	234	−0.02 (−0.11,0.08)	146	0.07 (−0.06,0.19)	252	0.09 (−0.00,0.19)
PFOS (branched isomers)	234	−0.03 (−0.14,0.08)	143	−0.01 (−0.21,0.19)	232	0.08 (−0.03,0.19)
PFOA	234	0.11 (−0.04,0.27)	146	−0.03 (−0.31,0.25)	252	0.19 (0.04,0.35)
PFHxS	234	−0.02 (−0.11,0.06)	146	0.00 (−0.14,0.15)	252	0.09 (0.01,0.18)
HDL cholesterol (mmol/L)						
PFOS (total)	234	0.02 (−0.02,0.05)	146	−0.01 (−0.05,0.03)	252	0.03 (−0.01,0.07)
PFOS (branched isomers)	234	−0.00 (−0.04,0.04)	143	−0.04 (−0.07,−0.00)	232	−0.01 (−0.05,0.03)
PFOA	234	0.03 (−0.02,0.08)	146	−0.02 (−0.07,0.02)	252	−0.01 (−0.07,0.05)
PFHxS	234	0.02 (−0.00,0.05)	146	−0.01 (−0.04,0.02)	252	0.00 (−0.02,0.03)
LDL cholesterol (mmol/L)						
PFOS (total)	218	−0.00 (−0.10,0.10)	146	0.08 (−0.01,0.18)	247	0.04 (−0.04,0.12)
PFOS (branched isomers)	218	−0.02 (−0.13,0.09)	143	0.05 (−0.06,0.17)	227	0.03 (−0.07,0.13)
PFOA	218	0.12 (−0.03,0.27)	146	0.07 (−0.07,0.21)	247	0.13 (−0.01,0.26)
PFHxS	218	−0.03 (−0.11,0.05)	146	0.02 (−0.05,0.10)	247	0.06 (−0.01,0.13)
Total:HDL cholesterol ratio						
PFOS (total)	234	−0.06 (−0.17,0.05)	146	0.09 (−0.06,0.24)	252	0.00 (−0.11,0.11)
PFOS (branched isomers)	234	−0.02 (−0.15,0.11)	143	0.09 (−0.12,0.30)	232	0.09 (−0.03,0.21)
PFOA	234	−0.02 (−0.22,0.19)	146	0.03 (−0.28,0.34)	252	0.23 (0.06,0.40)
PFHxS	234	−0.07 (−0.16,0.01)	146	0.03 (−0.13,0.19)	252	0.06 (−0.03,0.16)
Triglycerides (mmol/L)						
PFOS (total)	234	−0.09 (−0.19,0.02)	146	0.08 (−0.07,0.23)	252	0.02 (−0.10,0.13)
PFOS (branched isomers)	234	−0.06 (−0.18,0.06)	143	0.05 (−0.10,0.19)	232	0.06 (−0.07,0.18)
PFOA	234	−0.00 (−0.16,0.16)	146	0.05 (−0.13,0.23)	252	0.15 (−0.01,0.30)
PFHxS	234	−0.07 (−0.15,0.01)	146	0.07 (−0.07,0.20)	252	0.04 (−0.05,0.12)
Serum creatinine (umol/L)						
PFOS (total)	234	0.02 (−1.42,1.45)	146	0.92 (−1.32,3.16)	252	0.16 (−0.93,1.26)
PFOS (branched isomers)	234	0.23 (−1.23,1.68)	143	−0.12 (−3.70,3.46)	232	−0.06 (−1.43,1.32)
PFOA	234	−1.29 (−5.28,2.70)	146	0.74 (−3.82,5.29)	252	0.13 (−1.65,1.92)
PFHxS	234	−1.03 (−2.00,−0.06)	146	0.23 (−2.25,2.70)	252	−0.20 (−1.33,0.93)
Urate (uric acid) (mmol/L)						
PFOS (total)	234	−0.00 (−0.01,0.01)	146	0.00 (−0.01,0.01)	252	0.00 (−0.00,0.01)
PFOS (branched isomers)	234	0.00 (−0.01,0.01)	143	−0.01 (−0.02,0.01)	232	0.01 (−0.00,0.02)

	Katherine, NT		Oakey, Qld		Williamtown, NSW	
	N Exposed	Difference[¶] (95% CI)	N Exposed	Difference[¶] (95% CI)	N Exposed	Difference[¶] (95% CI)
PFOA	234	0.01 (0.00,0.03)	146	0.01 (−0.01,0.02)	252	0.02 (0.01,0.03)
PFHxS	234	−0.01 (−0.01,0.00)	146	−0.00 (−0.01,0.01)	252	0.00 (−0.00,0.01)
eGFR (mL/min/1.73 m2) CKD-EPI formula						
PFOS (total)	233	0.07 (−1.18,1.32)	146	−1.37 (−3.22,0.47)	250	−0.09 (−1.11,0.94)
PFOS (branched isomers)	233	−0.27 (−1.65,1.11)	143	−0.71 (−3.37,1.96)	231	−0.05 (−1.31,1.21)
PFOA	233	0.26 (−2.61,3.13)	146	−1.36 (−4.57,1.85)	250	−0.17 (−1.92,1.59)
PFHxS	233	0.94 (−0.00,1.87)	146	−0.78 (−2.63,1.07)	250	0.15 (−0.86,1.15)
ALT (U/L)						
PFOS (total)	211	−0.94 (−1.98,0.10)	145	0.42 (−0.92,1.75)	249	0.07 (−0.82,0.96)
PFOS (branched isomers)	211	−0.92 (−2.14,0.30)	142	0.56 (−1.12,2.24)	229	0.63 (−0.47,1.72)
PFOA	211	−0.52 (−1.82,0.77)	145	0.73 (−0.70,2.16)	249	0.28 (−0.93,1.50)
PFHxS	211	−0.89 (−1.71,−0.08)	145	0.11 (−0.87,1.09)	249	−0.07 (−0.84,0.70)
AST (U/L)						
PFOS (total)	233	−0.76 (−1.79,0.26)	146	0.56 (−0.76,1.89)	251	−0.07 (−0.62,0.48)
PFOS (branched isomers)	233	−0.63 (−1.83,0.57)	143	0.07 (−1.08,1.22)	231	0.10 (−0.58,0.77)
PFOA	233	−0.08 (−1.25,1.09)	146	1.41 (0.34,2.48)	251	0.58 (−0.37,1.53)
PFHxS	233	−0.72 (−1.52,0.09)	146	0.47 (−0.51,1.45)	251	−0.36 (−0.90,0.19)
GGT (U/L)						
PFOS (total)	234	1.22 (−2.38,4.82)	146	0.48 (−2.27,3.23)	252	0.72 (−1.88,3.31)
PFOS (branched isomers)	234	0.71 (−3.33,4.75)	143	0.75 (−2.79,4.29)	232	0.73 (−1.98,3.44)
PFOA	234	0.44 (−3.27,4.16)	146	0.94 (−1.76,3.64)	252	1.09 (−1.91,4.10)
PFHxS	234	1.12 (−1.36,3.60)	146	0.10 (−2.03,2.23)	252	0.12 (−1.82,2.06)
ALP (U/L)						
PFOS (total)	234	0.25 (−2.07,2.57)	146	−0.68 (−2.73,1.37)	251	−1.15 (−2.99,0.69)
PFOS (branched isomers)	234	−0.18 (−2.69,2.33)	143	1.22 (−1.28,3.71)	231	0.68 (−1.48,2.83)
PFOA	234	1.71 (−1.33,4.74)	146	−0.81 (−3.57,1.95)	251	0.89 (−2.65,4.43)
PFHxS	234	−0.13 (−2.13,1.88)	146	0.27 (−1.49,2.03)	251	−0.75 (−2.56,1.07)
Serum albumin (g/L)						
PFOS (total)	234	−0.00 (−0.30,0.29)	146	0.44 (0.11,0.76)	252	0.08 (−0.16,0.31)
PFOS (branched isomers)	234	0.01 (−0.30,0.33)	143	0.42 (0.01,0.82)	232	0.12 (−0.17,0.41)
PFOA	234	0.34 (−0.21,0.90)	146	0.50 (0.03,0.97)	252	0.20 (−0.21,0.61)
PFHxS	234	−0.08 (−0.32,0.16)	146	0.23 (−0.02,0.48)	252	0.03 (−0.19,0.26)
Total protein (g/L)						
PFOS (total)	234	−0.03 (−0.44,0.38)	146	0.74 (0.20,1.28)	252	−0.17 (−0.57,0.22)
PFOS (branched isomers)	234	0.01 (−0.46,0.47)	143	0.56 (−0.05,1.16)	232	−0.04 (−0.53,0.45)
PFOA	234	0.55 (−0.09,1.19)	146	0.60 (−0.06,1.27)	252	0.39 (−0.18,0.96)

	Katherine, NT		Oakey, Qld		Williamtown, NSW	
	N Exposed	Difference¶ (95% CI)	N Exposed	Difference¶ (95% CI)	N Exposed	Difference¶ (95% CI)
PFHxS	234	−0.20 (−0.57,0.17)	146	0.46 (0.05,0.87)	252	−0.03 (−0.42,0.35)
TSH (mIU/L)						
PFOS (total)	234	−0.00 (−0.07,0.06)	146	−0.02 (−0.11,0.07)	251	0.01 (−0.05,0.07)
PFOS (branched isomers)	234	−0.00 (−0.08,0.07)	143	0.02 (−0.08,0.12)	231	−0.00 (−0.08,0.08)
PFOA	234	0.10 (−0.02,0.23)	146	0.10 (−0.04,0.23)	251	0.06 (−0.05,0.17)
PFHxS	234	−0.01 (−0.06,0.05)	146	−0.00 (−0.07,0.07)	251	−0.02 (−0.08,0.04)
Free T3 (pmol/L)						
PFOS (total)	234	−0.02 (−0.06,0.02)	146	0.01 (−0.05,0.08)	251	−0.00 (−0.05,0.04)
PFOS (branched isomers)	234	0.01 (−0.04,0.06)	143	0.01 (−0.07,0.09)	231	0.04 (−0.02,0.09)
PFOA	234	0.01 (−0.05,0.08)	146	−0.02 (−0.10,0.06)	251	0.01 (−0.07,0.08)
PFHxS	234	−0.01 (−0.04,0.03)	146	−0.01 (−0.07,0.04)	251	0.00 (−0.04,0.04)
Free T4 (pmol/L)						
PFOS (total)	233	0.01 (−0.10,0.11)	146	0.08 (−0.06,0.21)	251	−0.02 (−0.16,0.11)
PFOS (branched isomers)	233	0.05 (−0.07,0.18)	143	0.11 (−0.04,0.26)	231	0.03 (−0.13,0.18)
PFOA	233	0.07 (−0.12,0.25)	146	0.09 (−0.08,0.26)	251	−0.01 (−0.22,0.21)
PFHxS	233	−0.01 (−0.10,0.08)	146	0.06 (−0.05,0.17)	251	0.06 (−0.05,0.18)

N: sample size; NC: convergence not achieved.

¶ Adjusted for age, sex, level of education and gross household annual income. Age was modelled using a restricted cubic spline with 3 knots.

Estimated assuming an independence (rather than exchangeable) within-cluster correlation structure and cluster-robust standard errors.

Biochemical marker sensitivity analysis 4: exclusion of exposed participants who have not lived in the exposed communities in the last 10 years

Table A6-9. Adjusted prevalence ratios of adverse lipid, liver, kidney and thyroid function biomarker concentrations per doubling in PFAS serum concentrations for residents and workers of PFAS Management Areas, 2016–2020. Sensitivity analysis: excluding exposed participants who have not lived in the exposed communities in the last 10 years.

	Katherine, NT		Oakey, Qld		Williamtown, NSW	
	N (cases) Exposed	PR‡ (95% CI)	N (cases) Exposed	PR‡ (95% CI)	N (cases) Exposed	PR‡ (95% CI)
High total cholesterol (>5.5 mmol/L)						
PFOS (total)	228 (82)	1.06 (0.94,1.18)	143 (45)	1.03 (0.89,1.20)	246 (87)	1.11 (0.99,1.25)
PFOS (branched isomers)	228 (82)	1.03 (0.90,1.18)	140 (45)	1.00 (0.82,1.22)	226 (78)	1.15 (1.01,1.31)
PFOA	228 (82)	1.17 (0.93,1.47)	143 (45)	1.01 (0.78,1.31)	246 (87)	1.28 (1.06,1.56)
PFHxS	228 (82)	1.02 (0.93,1.13)	143 (45)	1.04 (0.91,1.18)	246 (87)	1.15 (1.04,1.28)
Low HDL cholesterol^						
PFOS (total)	228 (29)	0.86 (0.65,1.14)	143 (13)	0.88 (0.57,1.38)	246 (25)	0.90 (0.59,1.38)
PFOS (branched isomers)	228 (29)	0.92 (0.69,1.22)	140 (12)	0.94 (0.60,1.48)	226 (24)	1.01 (0.74,1.38)#
PFOA	228 (29)	0.77 (0.51,1.16)	143 (13)	1.24 (0.74,2.09)	246 (25)	1.05 (0.63,1.75)
PFHxS	228 (29)	0.85 (0.72,1.02)	143 (13)	1.09 (0.82,1.43)	246 (25)	0.99 (0.79,1.24)
High LDL cholesterol (>4 mmol/L)						
PFOS (total)	212 (33)	0.97 (0.75,1.26)	143 (18)	1.03 (0.80,1.31)	241 (39)	1.02 (0.85,1.22)
PFOS (branched isomers)	212 (33)	0.95 (0.71,1.26)	140 (18)	1.09 (0.83,1.42)	221 (33)	1.06 (0.87,1.29)
PFOA	212 (33)	1.09 (0.67,1.77)	143 (18)	0.97 (0.69,1.37)	241 (39)	1.42 (1.07,1.88)
PFHxS	212 (33)	0.95 (0.77,1.17)	143 (18)	1.02 (0.87,1.21)	241 (39)	1.07 (0.90,1.27)
High total:HDL cholesterol ratio (>4.5)						
PFOS (total)	228 (63)	0.90 (0.79,1.04)	143 (46)	1.08 (0.91,1.29)	246 (72)	1.02 (0.89,1.16)
PFOS (branched isomers)	228 (63)	0.98 (0.83,1.15)	140 (45)	1.20 (0.98,1.46)	226 (69)	1.07 (0.93,1.23)
PFOA	228 (63)	0.96 (0.74,1.23)	143 (46)	1.06 (0.83,1.36)	246 (72)	1.26 (0.99,1.61)
PFHxS	228 (63)	0.93 (0.83,1.05)	143 (46)	1.04 (0.91,1.19)	246 (72)	1.06 (0.95,1.19)
High triglycerides (>2 mmol/L)						
PFOS (total)	228 (78)	0.92 (0.79,1.06)	143 (62)	1.05 (0.91,1.22)	246 (81)	1.01 (0.88,1.16)
PFOS (branched isomers)	228 (78)	0.95 (0.82,1.11)	140 (60)	1.11 (0.93,1.32)	226 (79)	1.04 (0.90,1.21)
PFOA	228 (78)	1.09 (0.86,1.37)	143 (62)	1.21 (0.97,1.50)	246 (81)	1.11 (0.89,1.38)
PFHxS	228 (78)	0.92 (0.82,1.04)	143 (62)	1.07 (0.95,1.20)	246 (81)	1.02 (0.91,1.14)
High serum creatinine^						
PFOS (total)	228 (8)	0.82 (0.56,1.19)	143 (11)	1.20 (0.71,2.02)	246 (7)	1.09 (0.73,1.62)
PFOS (branched isomers)	228 (8)	0.90 (0.63,1.29)	140 (10)	1.21 (0.56,2.61)	226 (5)	0.92 (0.52,1.63)
PFOA	228 (8)	0.83 (0.29,2.38)	143 (11)	1.57 (0.44,5.61)	246 (7)	1.78 (1.32,2.41)

	Katherine, NT		Oakey, Qld		Williamtown, NSW	
	N (cases) Exposed	PR‡ (95% CI)	N (cases) Exposed	PR‡ (95% CI)	N (cases) Exposed	PR‡ (95% CI)
PFHxS	228 (8)	0.83 (0.65,1.07)	143 (11)	1.22 (0.75,2.00)	246 (7)	0.95 (0.59,1.52)
High urate (uric acid)^						
PFOS (total)	228 (17)	1.19 (0.97,1.46)	143 (7)	1.37 (0.90,2.09)	246 (18)	1.16 (0.88,1.52)
PFOS (branched isomers)	228 (17)	1.20 (0.96,1.51)	140 (6)	0.85 (0.38,1.92)	226 (15)	1.28 (0.91,1.79)#
PFOA	228 (17)	1.81 (0.97,3.38)	143 (7)	1.14 (0.31,4.16)	246 (18)	1.99 (1.26,3.13)
PFHxS	228 (17)	1.02 (0.83,1.27)	143 (7)	1.04 (0.56,1.91)	246 (18)	1.00 (0.74,1.36)
Low eGFR (<60 mL/min/1.73 m2) CKD-EPI formula						
PFOS (total)	228 (7)	0.89 (0.54,1.47)#	143 (9)	1.13 (0.63,2.05)	245 (9)	1.07 (0.76,1.51)
PFOS (branched isomers)	228 (7)	0.85 (0.55,1.31)	140 (9)	1.34 (0.55,3.29)	226 (7)	0.75 (0.52,1.08)
PFOA	228 (7)	0.68 (0.18,2.61)	143 (9)	1.54 (0.32,7.36)	245 (9)	1.27 (0.81,1.99)
PFHxS	228 (7)	0.83 (0.64,1.08)	143 (9)	1.14 (0.66,1.99)	245 (9)	0.96 (0.64,1.44)
High ALT^						
PFOS (total)	205 (11)	0.90 (0.53,1.53)	142 (10)	NC	243 (9)	NC
PFOS (branched isomers)	205 (11)	0.88 (0.48,1.60)	139 (9)	NC	223 (9)	NC
PFOA	205 (11)	0.74 (0.47,1.17)	142 (10)	NC	243 (9)	NC
PFHxS	205 (11)	0.89 (0.62,1.28)	142 (10)	NC	243 (9)	NC
High AST^						
PFOS (total)	227 (10)	0.85 (0.54,1.35)	143 (7)	1.27 (0.77,2.09)	245 (4)	NC
PFOS (branched isomers)	227 (10)	0.80 (0.45,1.43)	140 (5)	0.94 (0.47,1.87)	225 (4)	NC
PFOA	227 (10)	0.72 (0.44,1.19)	143 (7)	1.27 (0.83,1.95)	245 (4)	NC
PFHxS	227 (10)	0.87 (0.56,1.34)	143 (7)	1.21 (0.79,1.86)	245 (4)	NC
High GGT^						
PFOS (total)	228 (30)	0.94 (0.78,1.14)	143 (25)	1.06 (0.82,1.38)	246 (38)	1.13 (0.91,1.40)
PFOS (branched isomers)	228 (30)	0.92 (0.73,1.16)	140 (24)	1.13 (0.79,1.62)	226 (36)	1.10 (0.87,1.39)
PFOA	228 (30)	1.06 (0.77,1.46)	143 (25)	1.27 (0.80,2.02)	246 (38)	1.18 (0.83,1.66)
PFHxS	228 (30)	0.94 (0.81,1.08)	143 (25)	0.95 (0.76,1.20)	246 (38)	1.06 (0.91,1.24)
High ALP^						
PFOS (total)	228 (11)	NC	143 (7)	1.23 (0.79,1.93)	245 (15)	1.24 (0.95,1.62)
PFOS (branched isomers)	228 (11)	NC	140 (7)	1.51 (0.91,2.52)	225 (13)	1.43 (1.05,1.93)
PFOA	228 (11)	NC	143 (7)	0.88 (0.58,1.34)	245 (15)	1.81 (0.97,3.36)
PFHxS	228 (11)	NC	143 (7)	1.15 (0.78,1.70)	245 (15)	1.03 (0.77,1.37)
Abnormal TSH^						
PFOS (total)	228 (7)	1.15 (0.89,1.49)	143 (2)	0.41 (0.19,0.92)	245 (6)	1.57 (1.12,2.19)
PFOS (branched isomers)	228 (7)	1.14 (0.78,1.65)	140 (2)	0.39 (0.20,0.75)	225 (3)	NC
PFOA	228 (7)	1.47 (0.83,2.61)	143 (2)	4.48 (1.30,15.50)	245 (6)	1.30 (0.62,2.74)

	Katherine, NT		Oakey, Qld		Williamtown, NSW	
	N (cases) Exposed	PR‡ (95% CI)	N (cases) Exposed	PR‡ (95% CI)	N (cases) Exposed	PR‡ (95% CI)
PFHxS	228 (7)	0.97 (0.76,1.23)	143 (2)	0.56 (0.38,0.84)	245 (6)	1.41 (1.04,1.92)

N: sample size; PR: prevalence ratio; NC: convergence not achieved.

‡ Adjusted for age, sex, level of education and gross household annual income. Age was modelled using a restricted cubic spline with 3 knots.

^ Reference intervals vary by sex and age.

Estimated assuming an independence (rather than exchangeable) within-cluster correlation structure and cluster-robust standard errors.

Table A6-10. Differences in mean lipid, liver, kidney and thyroid function biomarker concentrations per doubling in PFAS serum concentrations for residents and workers of PFAS Management Areas, 2016–2020. Sensitivity analysis: excluding exposed participants who have not lived in the exposed communities in the last 10 years.

	Katherine, NT		Oakey, Qld		Williamtown, NSW	
	N Exposed	Difference[¶] (95% CI)	N Exposed	Difference[¶] (95% CI)	N Exposed	Difference[¶] (95% CI)
Total cholesterol (mmol/L)						
PFOS (total)	228	−0.02 (−0.12,0.08)	143	0.06 (−0.07,0.18)	246	0.11 (0.02,0.20)
PFOS (branched isomers)	228	−0.03 (−0.14,0.08)	140	−0.02 (−0.22,0.18)	226	0.08 (−0.03,0.19)
PFOA	228	0.11 (−0.05,0.26)	143	−0.02 (−0.31,0.26)	246	0.19 (0.03,0.35)
PFHxS	228	−0.03 (−0.11,0.06)	143	0.00 (−0.15,0.15)	246	0.10 (0.01,0.18)
HDL cholesterol (mmol/L)						
PFOS (total)	228	0.01 (−0.02,0.05)	143	−0.01 (−0.05,0.03)	246	0.03 (−0.01,0.07)
PFOS (branched isomers)	228	−0.00 (−0.04,0.03)	140	−0.04 (−0.08,−0.00)	226	−0.01 (−0.05,0.03)
PFOA	228	0.04 (−0.02,0.09)	143	−0.03 (−0.07,0.02)	246	−0.01 (−0.07,0.05)
PFHxS	228	0.02 (−0.01,0.04)	143	−0.01 (−0.04,0.02)	246	0.00 (−0.03,0.03)
LDL cholesterol (mmol/L)						
PFOS (total)	212	0.00 (−0.10,0.10)	143	0.07 (−0.02,0.17)	241	0.05 (−0.03,0.13)
PFOS (branched isomers)	212	−0.02 (−0.12,0.09)	140	0.05 (−0.07,0.16)	221	0.03 (−0.06,0.13)
PFOA	212	0.13 (−0.03,0.28)	143	0.08 (−0.06,0.22)	241	0.13 (−0.01,0.27)
PFHxS	212	−0.03 (−0.11,0.05)	143	0.02 (−0.05,0.10)	241	0.06 (−0.01,0.14)
Total:HDL cholesterol ratio						
PFOS (total)	228	−0.06 (−0.17,0.05)	143	0.08 (−0.07,0.23)	246	0.02 (−0.08,0.13)
PFOS (branched isomers)	228	−0.02 (−0.15,0.11)	140	0.09 (−0.12,0.30)	226	0.10 (−0.02,0.22)
PFOA	228	−0.04 (−0.24,0.16)	143	0.04 (−0.27,0.35)	246	0.22 (0.05,0.39)
PFHxS	228	−0.06 (−0.15,0.03)	143	0.03 (−0.13,0.19)	246	0.07 (−0.02,0.16)
Triglycerides (mmol/L)						
PFOS (total)	228	−0.09 (−0.19,0.02)	143	0.08 (−0.07,0.23)	246	0.05 (−0.05,0.14)
PFOS (branched isomers)	228	−0.06 (−0.18,0.06)	140	0.05 (−0.10,0.19)	226	0.07 (−0.05,0.19)
PFOA	228	−0.01 (−0.17,0.15)	143	0.06 (−0.12,0.24)	246	0.14 (−0.02,0.30)
PFHxS	228	−0.07 (−0.15,0.02)	143	0.07 (−0.07,0.20)	246	0.04 (−0.05,0.13)
Serum creatinine (umol/L)						
PFOS (total)	228	0.04 (−1.40,1.49)	143	0.85 (−1.39,3.09)	246	0.05 (−1.06,1.15)
PFOS (branched isomers)	228	0.24 (−1.22,1.71)	140	−0.21 (−3.80,3.38)	226	−0.20 (−1.60,1.21)
PFOA	228	−1.36 (−5.46,2.73)	143	0.73 (−3.84,5.31)	246	0.17 (−1.63,1.98)
PFHxS	228	−1.01 (−2.00,−0.02)	143	0.19 (−2.30,2.67)	246	−0.28 (−1.43,0.86)
Urate (uric acid) (mmol/L)						
PFOS (total)	228	0.00 (−0.01,0.01)	143	0.00 (−0.01,0.01)	246	0.00 (−0.00,0.01)

	Katherine, NT		Oakey, Qld		Williamtown, NSW	
	N Exposed	Difference¶ (95% CI)	N Exposed	Difference¶ (95% CI)	N Exposed	Difference¶ (95% CI)
PFOS (branched isomers)	228	0.00 (−0.01,0.01)	140	−0.01 (−0.02,0.01)	226	0.01 (−0.00,0.02)
PFOA	228	0.01 (0.00,0.03)	143	0.01 (−0.01,0.02)	246	0.02 (0.01,0.03)
PFHxS	228	−0.01 (−0.01,0.00)	143	−0.00 (−0.01,0.01)	246	0.00 (−0.00,0.01)
eGFR (mL/min/1.73 m2) CKD-EPI formula						
PFOS (total)	228	0.05 (−1.21,1.30)	143	−1.28 (−3.13,0.57)	245	0.03 (−1.01,1.06)
PFOS (branched isomers)	228	−0.27 (−1.66,1.11)	140	−0.57 (−3.24,2.11)	226	0.09 (−1.18,1.37)
PFOA	228	0.31 (−2.63,3.24)	143	−1.35 (−4.57,1.87)	245	−0.13 (−1.90,1.64)
PFHxS	228	0.91 (−0.04,1.86)	143	−0.72 (−2.57,1.14)	245	0.24 (−0.77,1.26)
ALT (U/L)						
PFOS (total)	205	−0.93 (−1.98,0.12)	142	0.38 (−0.97,1.72)	243	0.24 (−0.62,1.10)
PFOS (branched isomers)	205	−0.89 (−2.13,0.34)	139	0.56 (−1.13,2.24)	223	0.76 (−0.34,1.86)
PFOA	205	−0.51 (−1.85,0.83)	142	0.77 (−0.66,2.20)	243	0.19 (−1.03,1.42)
PFHxS	205	−0.89 (−1.73,−0.05)	142	0.12 (−0.87,1.11)	243	−0.01 (−0.79,0.76)
AST (U/L)						
PFOS (total)	227	−0.77 (−1.80,0.27)	143	0.55 (−0.78,1.89)	245	−0.07 (−0.63,0.49)
PFOS (branched isomers)	227	−0.63 (−1.84,0.59)	140	0.07 (−1.09,1.23)	225	0.10 (−0.59,0.79)
PFOA	227	0.07 (−1.11,1.24)	143	1.45 (0.39,2.52)	245	0.61 (−0.36,1.57)
PFHxS	227	−0.74 (−1.57,0.09)	143	0.48 (−0.50,1.46)	245	−0.35 (−0.90,0.20)
GGT (U/L)						
PFOS (total)	228	1.33 (−2.28,4.93)	143	0.48 (−2.28,3.23)	246	1.06 (−1.54,3.66)
PFOS (branched isomers)	228	0.85 (−3.20,4.91)	140	0.76 (−2.81,4.32)	226	1.04 (−1.67,3.75)
PFOA	228	0.46 (−3.32,4.24)	143	1.03 (−1.68,3.74)	246	1.00 (−2.07,4.06)
PFHxS	228	1.21 (−1.29,3.70)	143	0.12 (−2.01,2.25)	246	0.24 (−1.72,2.20)
ALP (U/L)						
PFOS (total)	228	0.39 (−1.93,2.72)	143	−0.34 (−2.33,1.66)	245	−1.06 (−2.92,0.81)
PFOS (branched isomers)	228	−0.05 (−2.57,2.48)	140	1.49 (−0.99,3.96)	225	0.77 (−1.40,2.94)
PFOA	228	1.55 (−1.55,4.66)	143	−0.79 (−3.51,1.94)	245	0.77 (−2.88,4.42)
PFHxS	228	0.11 (−1.90,2.12)	143	0.37 (−1.38,2.13)	245	−0.72 (−2.59,1.15)
Serum albumin (g/L)						
PFOS (total)	228	0.01 (−0.28,0.31)	143	0.44 (0.11,0.77)	246	0.10 (−0.14,0.34)
PFOS (branched isomers)	228	0.04 (−0.28,0.35)	140	0.42 (0.01,0.83)	226	0.13 (−0.17,0.43)
PFOA	228	0.39 (−0.18,0.95)	143	0.51 (0.04,0.98)	246	0.22 (−0.20,0.64)
PFHxS	228	−0.06 (−0.31,0.18)	143	0.23 (−0.02,0.48)	246	0.05 (−0.19,0.28)
Total protein (g/L)						
PFOS (total)	228	−0.02 (−0.44,0.39)	143	0.72 (0.18,1.26)	246	−0.17 (−0.56,0.23)
PFOS (branched isomers)	228	0.00 (−0.47,0.48)	140	0.54 (−0.07,1.14)	226	−0.05 (−0.55,0.45)

	Katherine, NT		Oakey, Qld		Williamtown, NSW	
	N Exposed	Difference¶ (95% CI)	N Exposed	Difference¶ (95% CI)	N Exposed	Difference¶ (95% CI)
PFOA	228	0.60 (−0.05,1.25)	143	0.63 (−0.03,1.30)	246	0.42 (−0.16,1.00)
PFHxS	228	−0.18 (−0.56,0.19)	143	0.46 (0.04,0.87)	246	−0.03 (−0.42,0.36)
TSH (mIU/L)						
PFOS (total)	228	−0.01 (−0.07,0.06)	143	−0.02 (−0.11,0.08)	245	0.01 (−0.05,0.07)
PFOS (branched isomers)	228	−0.01 (−0.08,0.07)	140	0.02 (−0.08,0.12)	225	0.00 (−0.07,0.08)
PFOA	228	0.10 (−0.03,0.23)	143	0.09 (−0.04,0.23)	245	0.09 (−0.01,0.19)
PFHxS	228	−0.01 (−0.06,0.05)	143	−0.00 (−0.07,0.07)	245	−0.01 (−0.07,0.04)
Free T3 (pmol/L)						
PFOS (total)	228	−0.01 (−0.05,0.03)	143	0.02 (−0.04,0.08)	245	−0.01 (−0.05,0.04)
PFOS (branched isomers)	228	0.01 (−0.04,0.06)	140	0.02 (−0.06,0.10)	225	0.04 (−0.01,0.10)
PFOA	228	0.01 (−0.05,0.08)	143	−0.02 (−0.10,0.06)	245	0.01 (−0.06,0.09)
PFHxS	228	−0.00 (−0.04,0.03)	143	−0.01 (−0.07,0.05)	245	0.00 (−0.04,0.04)
Free T4 (pmol/L)						
PFOS (total)	227	0.01 (−0.09,0.11)	143	0.07 (−0.07,0.21)	245	−0.03 (−0.17,0.10)
PFOS (branched isomers)	227	0.05 (−0.07,0.18)	140	0.10 (−0.05,0.25)	225	0.01 (−0.14,0.17)
PFOA	227	0.04 (−0.14,0.23)	143	0.09 (−0.08,0.27)	245	−0.01 (−0.23,0.21)
PFHxS	227	−0.01 (−0.10,0.08)	143	0.06 (−0.05,0.17)	245	0.06 (−0.06,0.18)

N: sample size; NC: convergence not achieved.

¶ Adjusted for age, sex, level of education and gross household annual income. Age was modelled using a restricted cubic spline with 3 knots.

Estimated assuming an independence (rather than exchangeable) within-cluster correlation structure and cluster-robust standard errors.

Biochemical marker sensitivity analysis 5: exclusion of exposed participants who have not lived in the exposed communities in the last 5 years

Table A6-11. Adjusted prevalence ratios of adverse lipid, liver, kidney and thyroid function biomarker concentrations per doubling in PFAS serum concentrations for residents and workers of PFAS Management Areas, 2016–2020. Sensitivity analysis: excluding exposed participants who have not lived in the exposed communities in the last 5 years.

	Katherine, NT		Oakey, Qld		Williamtown, NSW	
	N (cases) Exposed	PR‡ (95% CI)	N (cases) Exposed	PR‡ (95% CI)	N (cases) Exposed	PR‡ (95% CI)
High total cholesterol (>5.5 mmol/L)						
PFOS (total)	220 (81)	1.04 (0.93,1.17)	143 (45)	1.03 (0.89,1.20)	242 (86)	1.11 (0.99,1.24)
PFOS (branched isomers)	220 (81)	1.02 (0.89,1.17)	140 (45)	1.00 (0.82,1.22)	222 (77)	1.14 (1.00,1.29)
PFOA	220 (81)	1.16 (0.92,1.45)	143 (45)	1.01 (0.78,1.31)	242 (86)	1.29 (1.07,1.57)
PFHxS	220 (81)	1.02 (0.93,1.12)	143 (45)	1.04 (0.91,1.18)	242 (86)	1.14 (1.03,1.26)
Low HDL cholesterol^						
PFOS (total)	220 (29)	0.85 (0.64,1.12)	143 (13)	0.88 (0.57,1.38)	242 (25)	0.89 (0.59,1.34)
PFOS (branched isomers)	220 (29)	0.90 (0.67,1.20)	140 (12)	0.94 (0.60,1.48)	222 (24)	1.00 (0.73,1.37)#
PFOA	220 (29)	0.76 (0.51,1.13)	143 (13)	1.24 (0.74,2.09)	242 (25)	1.04 (0.63,1.71)
PFHxS	220 (29)	0.85 (0.71,1.01)	143 (13)	1.09 (0.82,1.43)	242 (25)	0.98 (0.79,1.22)
High LDL cholesterol (>4 mmol/L)						
PFOS (total)	204 (33)	0.95 (0.73,1.24)	143 (18)	1.03 (0.80,1.31)	237 (39)	1.01 (0.84,1.21)
PFOS (branched isomers)	204 (33)	0.92 (0.69,1.23)	140 (18)	1.09 (0.83,1.42)	217 (33)	1.05 (0.86,1.28)
PFOA	204 (33)	1.07 (0.66,1.75)	143 (18)	0.97 (0.69,1.37)	237 (39)	1.42 (1.08,1.89)
PFHxS	204 (33)	0.93 (0.76,1.15)	143 (18)	1.02 (0.87,1.21)	237 (39)	1.06 (0.90,1.26)
High total:HDL cholesterol ratio (>4.5)						
PFOS (total)	220 (63)	0.89 (0.77,1.02)	143 (46)	1.08 (0.91,1.29)	242 (72)	1.01 (0.89,1.16)
PFOS (branched isomers)	220 (63)	0.96 (0.82,1.13)	140 (45)	1.20 (0.98,1.46)	222 (69)	1.06 (0.92,1.22)
PFOA	220 (63)	0.94 (0.73,1.21)	143 (46)	1.06 (0.83,1.36)	242 (72)	1.26 (0.98,1.61)
PFHxS	220 (63)	0.92 (0.82,1.04)	143 (46)	1.04 (0.91,1.19)	242 (72)	1.06 (0.95,1.18)
High triglycerides (>2 mmol/L)						
PFOS (total)	220 (77)	0.91 (0.78,1.05)	143 (62)	1.05 (0.91,1.22)	242 (81)	1.01 (0.88,1.16)
PFOS (branched isomers)	220 (77)	0.94 (0.81,1.10)	140 (60)	1.11 (0.93,1.32)	222 (79)	1.04 (0.89,1.20)
PFOA	220 (77)	1.06 (0.84,1.35)	143 (62)	1.21 (0.97,1.50)	242 (81)	1.10 (0.88,1.37)
PFHxS	220 (77)	0.92 (0.82,1.03)	143 (62)	1.07 (0.95,1.20)	242 (81)	1.02 (0.91,1.13)
High serum creatinine^						
PFOS (total)	220 (8)	0.80 (0.55,1.17)	143 (11)	1.20 (0.71,2.02)	242 (7)	1.08 (0.73,1.61)
PFOS (branched isomers)	220 (8)	0.88 (0.61,1.27)	140 (10)	1.21 (0.56,2.61)	222 (5)	0.91 (0.52,1.61)
PFOA	220 (8)	0.83 (0.29,2.37)	143 (11)	1.57 (0.44,5.61)	242 (7)	1.76 (1.30,2.39)

	Katherine, NT		Oakey, Qld		Williamtown, NSW	
	N (cases) Exposed	PR‡ (95% CI)	N (cases) Exposed	PR‡ (95% CI)	N (cases) Exposed	PR‡ (95% CI)
PFHxS	220 (8)	0.82 (0.64,1.06)	143 (11)	1.22 (0.75,2.00)	242 (7)	0.94 (0.59,1.51)
High urate (uric acid)^						
PFOS (total)	220 (17)	1.18 (0.95,1.45)	143 (7)	1.37 (0.90,2.09)	242 (18)	1.15 (0.88,1.51)
PFOS (branched isomers)	220 (17)	1.18 (0.93,1.50)	140 (6)	0.85 (0.38,1.92)	222 (15)	1.26(0.90,1.78)#
PFOA	220 (17)	1.79 (0.95,3.38)	143 (7)	1.14 (0.31,4.16)	242 (18)	1.96 (1.25,3.09)
PFHxS	220 (17)	1.01 (0.81,1.26)	143 (7)	1.04 (0.56,1.91)	242 (18)	1.00 (0.74,1.35)
Low eGFR (<60 mL/min/1.73 m2) CKD-EPI formula						
PFOS (total)	220 (7)	0.86(0.52,1.42)#	143 (9)	1.13 (0.63,2.05)	241 (9)	1.07 (0.76,1.50)
PFOS (branched isomers)	220 (7)	0.82 (0.52,1.29)	140 (9)	1.34 (0.55,3.29)	222 (7)	0.75 (0.52,1.07)
PFOA	220 (7)	0.67 (0.17,2.64)	143 (9)	1.54 (0.32,7.36)	241 (9)	1.24 (0.79,1.94)
PFHxS	220 (7)	0.81 (0.63,1.05)	143 (9)	1.14 (0.66,1.99)	241 (9)	0.96 (0.64,1.43)
High ALT^						
PFOS (total)	198 (11)	0.88(0.51,1.50)	142 (10)	NC	239 (9)	NC
PFOS (branched isomers)	198 (11)	0.85 (0.46,1.58)	139 (9)	NC	219 (9)	NC
PFOA	198 (11)	0.71 (0.45,1.13)	142 (10)	NC	239 (9)	NC
PFHxS	198 (11)	0.87 (0.60,1.24)	142 (10)	NC	239 (9)	NC
High AST^						
PFOS (total)	219 (10)	0.82 (0.51,1.31)	143 (7)	1.27 (0.77,2.09)	241 (4)	NC
PFOS (branched isomers)	219 (10)	0.77 (0.43,1.39)	140 (5)	0.94 (0.47,1.87)	221 (4)	NC
PFOA	219 (10)	0.71 (0.43,1.16)	143 (7)	1.27 (0.83,1.95)	241 (4)	NC
PFHxS	219 (10)	0.85 (0.55,1.31)	143 (7)	1.21 (0.79,1.86)	241 (4)	NC
High GGT^						
PFOS (total)	220 (30)	0.93 (0.77,1.13)	143 (25)	1.06 (0.82,1.38)	242 (38)	1.13 (0.91,1.40)
PFOS (branched isomers)	220 (30)	0.90 (0.71,1.14)	140 (24)	1.13 (0.79,1.62)	222 (36)	1.09 (0.86,1.38)
PFOA	220 (30)	1.05 (0.77,1.45)	143 (25)	1.27 (0.80,2.02)	242 (38)	1.16 (0.83,1.64)
PFHxS	220 (30)	0.93 (0.80,1.08)	143 (25)	0.95 (0.76,1.20)	242 (38)	1.05 (0.90,1.23)
High ALP^						
PFOS (total)	220 (11)	NC	143 (7)	1.23 (0.79,1.93)	241 (15)	1.24 (0.95,1.62)
PFOS (branched isomers)	220 (11)	NC	140 (7)	1.51 (0.91,2.52)	221 (13)	1.42 (1.04,1.92)
PFOA	220 (11)	NC	143 (7)	0.88 (0.58,1.34)	241 (15)	1.78 (0.96,3.33)
PFHxS	220 (11)	NC	143 (7)	1.15 (0.78,1.70)	241 (15)	1.03 (0.77,1.37)
Abnormal TSH^						
PFOS (total)	220 (7)	1.13 (0.87,1.47)	143 (2)	0.41 (0.19,0.92)	241 (6)	1.56 (1.12,2.18)
PFOS (branched isomers)	220 (7)	1.11 (0.76,1.63)	140 (2)	0.39 (0.20,0.75)	221 (3)	NC
PFOA	220 (7)	1.45 (0.80,2.61)	143 (2)	4.48(1.30,15.50)	241 (6)	1.29 (0.61,2.73)

	Katherine, NT		Oakey, Qld		Williamtown, NSW	
	N (cases) Exposed	PR‡ (95% CI)	N (cases) Exposed	PR‡ (95% CI)	N (cases) Exposed	PR‡ (95% CI)
PFHxS	220 (7)	0.95 (0.76,1.20)	143 (2)	0.56 (0.38,0.84)	241 (6)	1.40 (1.03,1.91)

N: sample size; PR: prevalence ratio; NC: convergence not achieved.

‡ Adjusted for age, sex, level of education and gross household annual income. Age was modelled using a restricted cubic spline with 3 knots.

^ Reference intervals vary by sex and age.

Estimated assuming an independence (rather than exchangeable) within-cluster correlation structure and cluster-robust standard errors.

Table A6-12. Differences in mean lipid, liver, kidney and thyroid function biomarker concentrations per doubling in PFAS serum concentrations for residents and workers of PFAS Management Areas, 2016–2020. Sensitivity analysis: excluding exposed participants who have not lived in the exposed communities in the last 5 years.

	Katherine, NT		Oakey, Qld		Williamtown, NSW	
	N Exposed	Difference[¶] (95% CI)	N Exposed	Difference[¶] (95% CI)	N Exposed	Difference[¶] (95% CI)
Total cholesterol (mmol/L)						
PFOS (total)	220	−0.03 (−0.13,0.07)	143	0.06 (−0.07,0.18)	242	0.10 (0.01,0.20)
PFOS (branched isomers)	220	−0.05 (−0.16,0.06)	140	−0.02 (−0.22,0.18)	222	0.07 (−0.04,0.19)
PFOA	220	0.10 (−0.05,0.26)	143	−0.02 (−0.31,0.26)	242	0.20 (0.04,0.37)
PFHxS	220	−0.03 (−0.12,0.06)	143	0.00 (−0.15,0.15)	242	0.09 (0.00,0.18)
HDL cholesterol (mmol/L)						
PFOS (total)	220	0.01 (−0.02,0.05)	143	−0.01 (−0.05,0.03)	242	0.03 (−0.01,0.07)
PFOS (branched isomers)	220	−0.00 (−0.04,0.03)	140	−0.04 (−0.08,−0.00)	222	−0.01 (−0.05,0.03)
PFOA	220	0.03 (−0.03,0.09)	143	−0.03 (−0.07,0.02)	242	−0.01 (−0.07,0.05)
PFHxS	220	0.02 (−0.01,0.04)	143	−0.01 (−0.04,0.02)	242	0.00 (−0.03,0.03)
LDL cholesterol (mmol/L)						
PFOS (total)	204	−0.01 (−0.11,0.09)	143	0.07 (−0.02,0.17)	237	0.04 (−0.04,0.13)
PFOS (branched isomers)	204	−0.03 (−0.14,0.08)	140	0.05 (−0.07,0.16)	217	0.03 (−0.07,0.13)
PFOA	204	0.11 (−0.05,0.27)	143	0.08 (−0.06,0.22)	237	0.14 (0.00,0.28)
PFHxS	204	−0.04 (−0.12,0.05)	143	0.02 (−0.05,0.10)	237	0.06 (−0.01,0.14)
Total:HDL cholesterol ratio						
PFOS (total)	220	−0.07 (−0.18,0.04)	143	0.08 (−0.07,0.23)	242	0.02 (−0.08,0.13)
PFOS (branched isomers)	220	−0.03 (−0.16,0.10)	140	0.09 (−0.12,0.30)	222	0.10 (−0.02,0.22)
PFOA	220	−0.04 (−0.25,0.16)	143	0.04 (−0.27,0.35)	242	0.23 (0.06,0.40)
PFHxS	220	−0.07 (−0.16,0.02)	143	0.03 (−0.13,0.19)	242	0.07 (−0.03,0.16)
Triglycerides (mmol/L)						
PFOS (total)	220	−0.10 (−0.21,0.01)	143	0.08 (−0.07,0.23)	242	0.05 (−0.05,0.14)
PFOS (branched isomers)	220	−0.07 (−0.20,0.05)	140	0.05 (−0.10,0.19)	222	0.07 (−0.06,0.19)
PFOA	220	−0.02 (−0.19,0.14)	143	0.06 (−0.12,0.24)	242	0.14 (−0.02,0.30)
PFHxS	220	−0.07 (−0.16,0.01)	143	0.07 (−0.07,0.20)	242	0.04 (−0.05,0.13)
Serum creatinine (umol/L)						
PFOS (total)	220	−0.07 (−1.51,1.38)	143	0.85 (−1.39,3.09)	242	0.04 (−1.07,1.16)
PFOS (branched isomers)	220	0.16 (−1.34,1.66)	140	−0.21 (−3.80,3.38)	222	−0.17 (−1.59,1.24)
PFOA	220	−1.28 (−5.53,2.96)	143	0.73 (−3.84,5.31)	242	0.31 (−1.53,2.14)
PFHxS	220	−1.05 (−2.07,−0.04)	143	0.19 (−2.30,2.67)	242	−0.26 (−1.42,0.90)
Urate (uric acid) (mmol/L)						
PFOS (total)	220	−0.00 (−0.01,0.01)	143	0.00 (−0.01,0.01)	242	0.00 (−0.00,0.01)

	Katherine, NT		Oakey, Qld		Williamtown, NSW	
	N Exposed	Difference¶ (95% CI)	N Exposed	Difference¶ (95% CI)	N Exposed	Difference¶ (95% CI)
PFOS (branched isomers)	220	−0.00 (−0.01,0.01)	140	−0.01 (−0.02,0.01)	222	0.01 (−0.00,0.02)
PFOA	220	0.01 (0.00,0.03)	143	0.01 (−0.01,0.02)	242	0.02 (0.01,0.03)
PFHxS	220	−0.01 (−0.01,0.00)	143	−0.00 (−0.01,0.01)	242	0.00 (−0.00,0.01)
eGFR (mL/min/1.73 m2) CKD-EPI formula						
PFOS (total)	220	0.18 (−1.08,1.43)	143	−1.28 (−3.13,0.57)	241	0.04 (−1.00,1.08)
PFOS (branched isomers)	220	−0.18 (−1.59,1.24)	140	−0.57 (−3.24,2.11)	222	0.07 (−1.21,1.36)
PFOA	220	0.12 (−2.87,3.11)	143	−1.35 (−4.57,1.87)	241	−0.32 (−2.11,1.48)
PFHxS	220	0.97 (0.00,1.93)	143	−0.72 (−2.57,1.14)	241	0.22 (−0.81,1.24)
ALT (U/L)						
PFOS (total)	198	−1.09 (−2.18,−0.00)	142	0.38 (−0.97,1.72)	239	0.25 (−0.62,1.12)
PFOS (branched isomers)	198	−1.04 (−2.31,0.24)	139	0.56 (−1.13,2.24)	219	0.76 (−0.35,1.87)
PFOA	198	−0.66 (−2.10,0.79)	142	0.77 (−0.66,2.20)	239	0.20 (−1.04,1.44)
PFHxS	198	−1.00 (−1.88,−0.13)	142	0.12 (−0.87,1.11)	239	−0.01 (−0.79,0.78)
AST (U/L)						
PFOS (total)	219	−0.92 (−1.99,0.14)	143	0.55 (−0.78,1.89)	241	−0.07 (−0.63,0.50)
PFOS (branched isomers)	219	−0.78 (−2.02,0.47)	140	0.07 (−1.09,1.23)	221	0.07 (−0.62,0.77)
PFOA	219	−0.07 (−1.28,1.14)	143	1.45 (0.39,2.52)	241	0.60 (−0.37,1.57)
PFHxS	219	−0.83 (−1.67,0.02)	143	0.48 (−0.50,1.46)	241	−0.37 (−0.93,0.19)
GGT (U/L)						
PFOS (total)	220	1.22 (−2.49,4.93)	143	0.48 (−2.28,3.23)	242	1.03 (−1.60,3.66)
PFOS (branched isomers)	220	0.72 (−3.46,4.91)	140	0.76 (−2.81,4.32)	222	0.96 (−1.78,3.70)
PFOA	220	0.49 (−3.42,4.40)	143	1.03 (−1.68,3.74)	242	1.03 (−2.08,4.14)
PFHxS	220	1.12 (−1.42,3.66)	143	0.12 (−2.01,2.25)	242	0.20 (−1.79,2.19)
ALP (U/L)						
PFOS (total)	220	0.16 (−2.12,2.44)	143	−0.34 (−2.33,1.66)	241	−1.06 (−2.94,0.82)
PFOS (branched isomers)	220	−0.19 (−2.70,2.31)	140	1.49 (−0.99,3.96)	221	0.75 (−1.44,2.95)
PFOA	220	1.37 (−1.73,4.48)	143	−0.79 (−3.51,1.94)	241	0.73 (−2.94,4.39)
PFHxS	220	0.04 (−1.96,2.04)	143	0.37 (−1.38,2.13)	241	−0.73 (−2.60,1.13)
Serum albumin (g/L)						
PFOS (total)	220	−0.03 (−0.32,0.27)	143	0.44 (0.11,0.77)	242	0.09 (−0.15,0.33)
PFOS (branched isomers)	220	−0.00 (−0.31,0.31)	140	0.42 (0.01,0.83)	222	0.11 (−0.19,0.41)
PFOA	220	0.31 (−0.28,0.91)	143	0.51 (0.04,0.98)	242	0.21 (−0.21,0.63)
PFHxS	220	−0.08 (−0.32,0.17)	143	0.23 (−0.02,0.48)	242	0.03 (−0.21,0.26)
Total protein (g/L)						
PFOS (total)	220	−0.06 (−0.49,0.37)	143	0.72 (0.18,1.26)	242	−0.17 (−0.57,0.24)
PFOS (branched isomers)	220	−0.03 (−0.51,0.46)	140	0.54 (−0.07,1.14)	222	−0.07 (−0.57,0.44)

	Katherine, NT		Oakey, Qld		Williamtown, NSW	
	N Exposed	Difference¶ (95% CI)	N Exposed	Difference¶ (95% CI)	N Exposed	Difference¶ (95% CI)
PFOA	220	0.63 (−0.07,1.33)	143	0.63 (−0.03,1.30)	242	0.37 (−0.22,0.96)
PFHxS	220	−0.19 (−0.58,0.20)	143	0.46 (0.04,0.87)	242	−0.05 (−0.44,0.35)
TSH (mIU/L)						
PFOS (total)	220	−0.01 (−0.08,0.06)	143	−0.02 (−0.11,0.08)	241	0.01 (−0.06,0.07)
PFOS (branched isomers)	220	−0.01 (−0.09,0.07)	140	0.02 (−0.08,0.12)	221	−0.00 (−0.08,0.07)
PFOA	220	0.11 (−0.03,0.24)	143	0.09 (−0.04,0.23)	241	0.09 (−0.01,0.19)
PFHxS	220	−0.01 (−0.07,0.04)	143	−0.00 (−0.07,0.07)	241	−0.01 (−0.07,0.04)
Free T3 (pmol/L)						
PFOS (total)	220	−0.02 (−0.06,0.02)	143	0.02 (−0.04,0.08)	241	−0.00 (−0.04,0.04)
PFOS (branched isomers)	220	0.00 (−0.05,0.06)	140	0.02 (−0.06,0.10)	221	0.05 (−0.01,0.10)
PFOA	220	−0.00 (−0.07,0.06)	143	−0.02 (−0.10,0.06)	241	0.01 (−0.07,0.08)
PFHxS	220	−0.01 (−0.04,0.03)	143	−0.01 (−0.07,0.05)	241	0.01 (−0.03,0.05)
Free T4 (pmol/L)						
PFOS (total)	219	0.00 (−0.10,0.11)	143	0.07 (−0.07,0.21)	241	−0.03 (−0.16,0.11)
PFOS (branched isomers)	219	0.05 (−0.08,0.18)	140	0.10 (−0.05,0.25)	221	0.01 (−0.15,0.17)
PFOA	219	0.02 (−0.17,0.21)	143	0.09 (−0.08,0.27)	241	−0.05 (−0.27,0.17)
PFHxS	219	−0.01 (−0.10,0.08)	143	0.06 (−0.05,0.17)	241	0.05 (−0.07,0.17)

N: sample size; NC: convergence not achieved.

¶ Adjusted for age, sex, level of education and gross household annual income. Age was modelled using a restricted cubic spline with 3 knots.

Estimated assuming an independence (rather than exchangeable) within-cluster correlation structure and cluster-robust standard errors.

Biochemical marker sensitivity analysis 6: exclusion of exposed participants who have not lived in the exposed communities in the last 10 years and past workers

Table A6-13. Adjusted prevalence ratios of adverse lipid, liver, kidney and thyroid function biomarker concentrations per doubling in PFAS serum concentrations for residents and workers of PFAS Management Areas, 2016–2020. Sensitivity analysis: excluding exposed participants who have not lived in the exposed communities in the last 10 years and past workers.

	Katherine, NT		Oakey, Qld		Williamtown, NSW	
	N (cases) Exposed	PR‡ (95% CI)	N (cases) Exposed	PR‡ (95% CI)	N (cases) Exposed	PR‡ (95% CI)
High total cholesterol (>5.5 mmol/L)						
PFOS (total)	210 (75)	1.05 (0.93,1.19)	109 (35)	1.00 (0.84,1.19)	184 (62)	1.12 (0.98,1.29)
PFOS (branched isomers)	210 (75)	1.02 (0.88,1.18)	107 (35)	0.97 (0.76,1.23)	165 (54)	1.17 (1.00,1.38)
PFOA	210 (75)	1.15 (0.91,1.46)	109 (35)	0.92 (0.71,1.21)	184 (62)	1.42 (1.16,1.73)
PFHxS	210 (75)	1.03 (0.93,1.14)	109 (35)	1.04 (0.90,1.20)	184 (62)	1.16 (1.03,1.32)
Low HDL cholesterol^						
PFOS (total)	210 (24)	0.86 (0.63,1.17)	109 (10)	0.79 (0.47,1.31)	184 (19)	0.91 (0.64,1.28)
PFOS (branched isomers)	210 (24)	0.90 (0.66,1.23)	107 (9)	0.74 (0.41,1.35)	165 (18)	1.22 (0.82,1.81)
PFOA	210 (24)	0.77 (0.49,1.22)	109 (10)	1.14 (0.58,2.24)	184 (19)	1.26 (0.78,2.05)
PFHxS	210 (24)	0.83 (0.69,1.01)	109 (10)	1.10 (0.80,1.52)	184 (19)	0.91 (0.73,1.13)
High LDL cholesterol (>4 mmol/L)						
PFOS (total)	194 (29)	0.95 (0.70,1.29)	109 (15)	1.01 (0.77,1.33)	181 (27)	1.08 (0.87,1.34)
PFOS (branched isomers)	194 (29)	0.95 (0.68,1.31)	107 (15)	1.14 (0.82,1.59)	162 (22)	1.11 (0.86,1.42)
PFOA	194 (29)	1.01 (0.58,1.77)	109 (15)	0.87 (0.60,1.26)	181 (27)	1.53 (1.10,2.13)
PFHxS	194 (29)	0.95 (0.73,1.23)	109 (15)	1.03 (0.85,1.24)	181 (27)	1.05 (0.84,1.30)
High total:HDL cholesterol ratio (>4.5)						
PFOS (total)	210 (55)	0.86 (0.75,1.00)	109 (33)	0.98 (0.79,1.21)	184 (50)	1.01 (0.86,1.18)
PFOS (branched isomers)	210 (55)	0.95 (0.79,1.13)	107 (32)	1.07 (0.85,1.36)	165 (47)	1.02 (0.85,1.24)
PFOA	210 (55)	0.96 (0.72,1.27)	109 (33)	1.08 (0.79,1.46)	184 (50)	1.28 (0.95,1.73)
PFHxS	210 (55)	0.93 (0.82,1.05)	109 (33)	1.00 (0.85,1.18)	184 (50)	1.05 (0.91,1.21)
High triglycerides (>2 mmol/L)						
PFOS (total)	210 (69)	0.88 (0.76,1.04)	109 (49)	0.99 (0.84,1.18)	184 (61)	0.99 (0.85,1.15)
PFOS (branched isomers)	210 (69)	0.91 (0.77,1.07)	107 (48)	1.10 (0.88,1.36)	165 (59)	0.98 (0.81,1.18)
PFOA	210 (69)	1.10 (0.85,1.42)	109 (49)	1.23 (0.97,1.56)	184 (61)	1.13 (0.87,1.48)
PFHxS	210 (69)	0.91 (0.80,1.04)	109 (49)	1.08 (0.94,1.23)	184 (61)	0.99 (0.87,1.13)
High serum creatinine^						
PFOS (total)	210 (7)	0.83 (0.54,1.27)	109 (7)	1.88 (1.13,3.13)	184 (7)	1.04 (0.70,1.54)
PFOS (branched isomers)	210 (7)	0.94 (0.63,1.39)	107 (6)	3.60 (1.74,7.41)	165 (5)	0.90 (0.47,1.71)

	Katherine, NT		Oakey, Qld		Williamtown, NSW	
	N (cases) Exposed	PR‡ (95% CI)	N (cases) Exposed	PR‡ (95% CI)	N (cases) Exposed	PR‡ (95% CI)
PFOA	210 (7)	0.76 (0.23,2.50)	109 (7)	5.95 (2.27,15.56)	184 (7)	1.74 (1.26,2.41)
PFHxS	210 (7)	0.82 (0.61,1.11)	109 (7)	1.66 (1.04,2.65)	184 (7)	0.90 (0.54,1.50)
High urate (uric acid)^						
PFOS (total)	210 (15)	1.17 (0.92,1.48)	109 (4)	1.61 (1.02,2.53)	184 (17)	1.09 (0.81,1.46)
PFOS (branched isomers)	210 (15)	1.21 (0.93,1.58)	107 (3)	1.46 (0.91,2.34)	165 (14)	1.30 (0.89,1.90)#
PFOA	210 (15)	1.64 (0.81,3.32)	109 (4)	2.30 (1.01,5.25)	184 (17)	1.89 (1.19,2.99)
PFHxS	210 (15)	1.03 (0.81,1.32)	109 (4)	1.53 (0.96,2.44)	184 (17)	0.95 (0.69,1.33)
Low eGFR (<60 mL/min/1.73 m2) CKD-EPI formula						
PFOS (total)	210 (6)	0.89 (0.50,1.57)#	109 (6)	1.77 (1.07,2.95)	183 (9)	1.02 (0.73,1.43)
PFOS (branched isomers)	210 (6)	0.84 (0.53,1.33)	107 (6)	3.22 (1.86,5.58)	165 (7)	0.70 (0.45,1.09)
PFOA	210 (6)	0.58 (0.12,2.78)	109 (6)	7.72 (3.19,18.69)	183 (9)	1.21 (0.74,1.99)
PFHxS	210 (6)	0.81 (0.57,1.16)#	109 (6)	1.44 (0.92,2.25)	183 (9)	0.94 (0.62,1.44)
High ALT^						
PFOS (total)	187 (9)	0.81 (0.48,1.37)	108 (9)	NC	181 (6)	NC
PFOS (branched isomers)	187 (9)	0.69 (0.39,1.22)	106 (9)	NC	162 (6)	NC
PFOA	187 (9)	0.76 (0.51,1.14)	108 (9)	NC	181 (6)	NC
PFHxS	187 (9)	0.79 (0.55,1.15)	108 (9)	NC	181 (6)	NC
High AST^						
PFOS (total)	209 (8)	0.96 (0.61,1.50)	109 (5)	1.06 (0.57,1.94)	183 (3)	NC
PFOS (branched isomers)	209 (8)	0.92 (0.50,1.69)	107 (4)	0.77 (0.32,1.82)	164 (3)	NC
PFOA	209 (8)	0.82 (0.50,1.34)	109 (5)	1.14 (0.70,1.86)	183 (3)	NC
PFHxS	209 (8)	0.97 (0.64,1.49)	109 (5)	1.06 (0.61,1.85)	183 (3)	NC
High GGT^						
PFOS (total)	210 (25)	0.89 (0.73,1.08)	109 (20)	1.10 (0.83,1.47)	184 (24)	1.22 (0.94,1.58)
PFOS (branched isomers)	210 (25)	0.83 (0.65,1.05)	107 (20)	1.39 (1.07,1.81)	165 (22)	1.22 (0.92,1.62)
PFOA	210 (25)	0.90 (0.63,1.28)	109 (20)	1.55 (1.03,2.32)	184 (24)	1.48 (0.97,2.27)
PFHxS	210 (25)	0.89 (0.76,1.05)	109 (20)	1.02 (0.79,1.30)	184 (24)	1.08 (0.89,1.31)
High ALP^						
PFOS (total)	210 (11)	NC	109 (5)	1.30 (0.84,2.00)	183 (10)	1.13 (0.89,1.45)
PFOS (branched isomers)	210 (11)	NC	107 (5)	1.26 (0.59,2.71)	164 (8)	1.16 (0.82,1.64)
PFOA	210 (11)	NC	109 (5)	0.98 (0.51,1.90)	183 (10)	1.26 (0.62,2.53)
PFHxS	210 (11)	NC	109 (5)	1.16 (0.76,1.79)	183 (10)	1.19 (1.00,1.42)
Abnormal TSH^						
PFOS (total)	210 (7)	1.13 (0.87,1.47)	109 (1)	0.68 (0.41,1.14)	184 (6)	1.51 (1.07,2.13)
PFOS (branched isomers)	210 (7)	1.11 (0.76,1.63)	107 (1)	0.53 (0.24,1.17)	165 (3)	NC

	Katherine, NT		Oakey, Qld		Williamtown, NSW	
	N (cases) Exposed	PR‡ (95% CI)	N (cases) Exposed	PR‡ (95% CI)	N (cases) Exposed	PR‡ (95% CI)
PFOA	210 (7)	1.45 (0.81,2.61)	109 (1)	NC	184 (6)	1.34 (0.63,2.85)
PFHxS	210 (7)	0.92 (0.70,1.21)	109 (1)	0.57 (0.32,1.01)	184 (6)	1.35 (0.99,1.85)

N: sample size; PR: prevalence ratio; NC: convergence not achieved.

‡ Adjusted for age, sex, level of education and gross household annual income. Age was modelled using a restricted cubic spline with 3 knots.

^ Reference intervals vary by sex and age.

Estimated assuming an independence (rather than exchangeable) within-cluster correlation structure and cluster-robust standard errors.

Table A6-14. Differences in mean lipid, liver, kidney and thyroid function biomarker concentrations per doubling in PFAS serum concentrations for residents and workers of PFAS Management Areas, 2016–2020. Sensitivity analysis: excluding exposed participants who have not lived in the exposed communities in the last 10 years and past workers.

	Katherine, NT		Oakey, Qld		Williamtown, NSW	
	N Exposed	Difference¶ (95% CI)	N Exposed	Difference¶ (95% CI)	N Exposed	Difference¶ (95% CI)
Total cholesterol (mmol/L)						
PFOS (total)	210	−0.03 (−0.14,0.08)	109	0.05 (−0.09,0.19)	184	0.09 (−0.02,0.19)
PFOS (branched isomers)	210	−0.05 (−0.17,0.07)	107	0.07 (−0.11,0.24)	165	0.04 (−0.10,0.18)
PFOA	210	0.11 (−0.05,0.28)	109	0.07 (−0.12,0.25)	184	0.23 (0.03,0.43)
PFHxS	210	−0.02 (−0.11,0.07)	109	0.06 (−0.06,0.18)	184	0.09 (−0.02,0.20)
HDL cholesterol (mmol/L)						
PFOS (total)	210	0.02 (−0.01,0.05)	109	0.00 (−0.04,0.04)	184	0.03 (−0.01,0.07)
PFOS (branched isomers)	210	0.00 (−0.03,0.04)	107	−0.02 (−0.07,0.03)	165	−0.02 (−0.07,0.02)
PFOA	210	0.05 (−0.01,0.10)	109	−0.04 (−0.09,0.02)	184	−0.00 (−0.07,0.06)
PFHxS	210	0.02 (−0.00,0.05)	109	−0.01 (−0.04,0.03)	184	0.01 (−0.02,0.04)
LDL cholesterol (mmol/L)						
PFOS (total)	194	−0.01 (−0.12,0.10)	109	0.04 (−0.07,0.15)	181	0.04 (−0.05,0.13)
PFOS (branched isomers)	194	−0.03 (−0.15,0.09)	107	0.05 (−0.10,0.20)	162	0.02 (−0.10,0.14)
PFOA	194	0.13 (−0.04,0.30)	109	0.04 (−0.14,0.22)	181	0.11 (−0.07,0.29)
PFHxS	194	−0.02 (−0.12,0.07)	109	0.02 (−0.07,0.12)	181	0.07 (−0.03,0.16)
Total:HDL cholesterol ratio						
PFOS (total)	210	−0.09 (−0.19,0.02)	109	0.03 (−0.13,0.18)	184	0.00 (−0.11,0.12)
PFOS (branched isomers)	210	−0.05 (−0.17,0.08)	107	0.09 (−0.08,0.25)	165	0.08 (−0.07,0.24)
PFOA	210	−0.07 (−0.28,0.13)	109	0.17 (−0.03,0.36)	184	0.27 (0.05,0.49)
PFHxS	210	−0.08 (−0.16,0.01)	109	0.08 (−0.05,0.21)	184	0.05 (−0.07,0.17)
Triglycerides (mmol/L)						
PFOS (total)	210	−0.11 (−0.22,−0.01)	109	0.05 (−0.12,0.23)	184	0.02 (−0.08,0.13)
PFOS (branched isomers)	210	−0.10 (−0.21,0.02)	107	0.05 (−0.11,0.20)	165	0.02 (−0.13,0.18)
PFOA	210	−0.02 (−0.18,0.15)	109	0.12 (−0.06,0.29)	184	0.15 (−0.05,0.36)
PFHxS	210	−0.08 (−0.15,0.00)	109	0.11 (−0.06,0.27)	184	−0.01 (−0.12,0.10)
Serum creatinine (umol/L)						
PFOS (total)	210	0.16 (−1.39,1.71)	109	2.05 (−0.25,4.35)	184	0.17 (−1.04,1.39)
PFOS (branched isomers)	210	0.40 (−1.15,1.95)	107	2.30 (−0.84,5.44)	165	0.20 (−1.47,1.86)
PFOA	210	−1.47 (−6.02,3.09)	109	3.24 (0.31,6.16)	184	1.27 (−0.77,3.32)
PFHxS	210	−0.90 (−1.99,0.18)	109	1.47 (−0.55,3.48)	184	−0.09 (−1.54,1.37)
Urate (uric acid) (mmol/L)						
PFOS (total)	210	−0.00 (−0.01,0.01)	109	0.00 (−0.01,0.01)	184	0.00 (−0.01,0.01)

	Katherine, NT		Oakey, Qld		Williamtown, NSW	
	N Exposed	Difference¶ (95% CI)	N Exposed	Difference¶ (95% CI)	N Exposed	Difference¶ (95% CI)
PFOS (branched isomers)	210	0.00 (−0.01,0.01)	107	−0.00 (−0.02,0.01)	165	0.01 (−0.00,0.02)
PFOA	210	0.01 (−0.00,0.03)	109	0.02 (0.00,0.03)	184	0.03 (0.01,0.04)
PFHxS	210	−0.01 (−0.01,0.00)	109	0.00 (−0.01,0.01)	184	0.00 (−0.00,0.01)
eGFR (mL/min/1.73 m2) CKD-EPI formula						
PFOS (total)	210	−0.04 (−1.37,1.30)	109	−2.27 (−4.22,−0.33)	183	−0.09 (−1.21,1.03)
PFOS (branched isomers)	210	−0.42 (−1.90,1.05)	107	−2.53 (−5.16,0.09)	165	−0.33 (−1.83,1.16)
PFOA	210	0.39 (−2.87,3.64)	109	−2.93 (−5.51,−0.35)	183	−1.30 (−3.31,0.70)
PFHxS	210	0.81 (−0.23,1.85)	109	−1.72 (−3.46,0.02)	183	0.12 (−1.14,1.37)
ALT (U/L)						
PFOS (total)	187	−1.29 (−2.25,−0.34)	108	−0.06 (−1.57,1.46)	181	−0.19 (−1.11,0.72)
PFOS (branched isomers)	187	−1.42 (−2.46,−0.38)	106	0.40 (−1.85,2.66)	162	0.23 (−0.95,1.41)
PFOA	187	−0.91 (−2.23,0.41)	108	0.36 (−1.42,2.14)	181	−0.17 (−1.46,1.13)
PFHxS	187	−1.24 (−2.04,−0.43)	108	−0.28 (−1.51,0.96)	181	−0.56 (−1.43,0.32)
AST (U/L)						
PFOS (total)	209	−0.67 (−1.72,0.37)	109	0.22 (−1.33,1.77)	183	−0.29 (−0.94,0.36)
PFOS (branched isomers)	209	−0.49 (−1.76,0.79)	107	−0.15 (−1.68,1.38)	164	−0.02 (−0.89,0.84)
PFOA	209	0.10 (−1.01,1.21)	109	1.27 (−0.05,2.60)	183	0.20 (−0.94,1.35)
PFHxS	209	−0.63 (−1.47,0.22)	109	0.24 (−1.07,1.56)	183	−0.53 (−1.23,0.17)
GGT (U/L)						
PFOS (total)	210	0.85 (−2.75,4.45)	109	0.60 (−2.68,3.87)	184	1.10 (−2.04,4.23)
PFOS (branched isomers)	210	0.24 (−3.95,4.43)	107	2.00 (−2.55,6.55)	165	1.21 (−2.28,4.70)
PFOA	210	−0.32 (−4.31,3.67)	109	2.02 (−1.28,5.31)	184	1.53 (−2.15,5.20)
PFHxS	210	0.91 (−1.60,3.42)	109	0.51 (−2.20,3.22)	184	0.00 (−2.53,2.54)
ALP (U/L)						
PFOS (total)	210	0.28 (−2.20,2.75)	109	−0.25 (−2.42,1.92)	183	−2.14 (−4.04,−0.24)
PFOS (branched isomers)	210	−0.05 (−2.75,2.66)	107	0.82 (−2.11,3.76)	164	−0.35 (−2.72,2.03)
PFOA	210	0.92 (−2.44,4.28)	109	−1.23 (−4.74,2.28)	183	−0.59 (−5.11,3.94)
PFHxS	210	0.13 (−2.10,2.36)	109	0.67 (−1.59,2.93)	183	−0.89 (−3.10,1.32)
Serum albumin (g/L)						
PFOS (total)	210	0.07 (−0.25,0.38)	109	0.44 (0.11,0.78)	184	0.15 (−0.12,0.42)
PFOS (branched isomers)	210	0.11 (−0.22,0.45)	107	0.46 (−0.01,0.93)	165	0.22 (−0.12,0.56)
PFOA	210	0.50 (−0.11,1.12)	109	0.51 (−0.04,1.06)	184	0.16 (−0.36,0.68)
PFHxS	210	0.01 (−0.26,0.27)	109	0.23 (−0.04,0.50)	184	0.02 (−0.26,0.29)
Total protein (g/L)						
PFOS (total)	210	0.08 (−0.35,0.51)	109	0.69 (0.10,1.28)	184	−0.08 (−0.54,0.38)

	Katherine, NT		Oakey, Qld		Williamtown, NSW	
	N Exposed	Difference¶ (95% CI)	N Exposed	Difference¶ (95% CI)	N Exposed	Difference¶ (95% CI)
PFOS (branched isomers)	210	0.15 (−0.34,0.65)	107	0.63 (−0.12,1.37)	165	0.17 (−0.43,0.77)
PFOA	210	0.77 (0.08,1.45)	109	0.71 (−0.14,1.56)	184	0.42 (−0.26,1.10)
PFHxS	210	−0.08 (−0.49,0.33)	109	0.56 (0.08,1.04)	184	−0.01 (−0.48,0.47)
TSH (mIU/L)						
PFOS (total)	210	−0.01 (−0.08,0.05)	109	−0.00 (−0.10,0.10)	184	0.03 (−0.04,0.10)
PFOS (branched isomers)	210	−0.02 (−0.10,0.07)	107	0.04 (−0.08,0.17)	165	0.02 (−0.07,0.11)
PFOA	210	0.10 (−0.04,0.25)	109	0.11 (−0.06,0.29)	184	0.09 (−0.04,0.21)
PFHxS	210	−0.02 (−0.07,0.04)	109	−0.00 (−0.09,0.08)	184	−0.01 (−0.08,0.05)
Free T3 (pmol/L)						
PFOS (total)	210	−0.02 (−0.06,0.02)	109	0.06 (−0.01,0.13)	184	−0.01 (−0.05,0.04)
PFOS (branched isomers)	210	−0.00 (−0.06,0.05)	107	0.10 (0.01,0.19)	165	0.06 (−0.01,0.13)
PFOA	210	0.01 (−0.06,0.08)	109	0.01 (−0.09,0.11)	184	−0.00 (−0.09,0.08)
PFHxS	210	−0.01 (−0.05,0.03)	109	0.04 (−0.02,0.10)	184	0.02 (−0.03,0.07)
Free T4 (pmol/L)						
PFOS (total)	209	0.03 (−0.08,0.14)	109	0.07 (−0.09,0.23)	184	−0.00 (−0.16,0.16)
PFOS (branched isomers)	209	0.07 (−0.05,0.20)	107	0.11 (−0.09,0.30)	165	0.11 (−0.08,0.30)
PFOA	209	0.08 (−0.12,0.28)	109	0.14 (−0.10,0.38)	184	0.08 (−0.20,0.35)
PFHxS	209	−0.01 (−0.11,0.09)	109	0.08 (−0.07,0.23)	184	0.08 (−0.06,0.23)

N: sample size; NC: convergence not achieved.

¶ Adjusted for age, sex, level of education and gross household annual income. Age was modelled using a restricted cubic spline with 3 knots.

Estimated assuming an independence (rather than exchangeable) within-cluster correlation structure and cluster-robust standard errors.

Biochemical marker sensitivity analysis 7: exclusion of participants who have not lived in a PFAS Management Area for at least 1 year

Table A6-15. Adjusted prevalence ratios of adverse lipid, liver, kidney and thyroid function biomarker concentrations per doubling in PFAS serum concentrations for residents and workers of PFAS Management Areas, 2016–2020. Sensitivity analysis: excluding exposed participants who have not lived in the exposed communities for at least 1 year.

	Katherine, NT		Oakey, Qld		Williamtown, NSW	
	N (cases) Exposed	PR‡ (95% CI)	N (cases) Exposed	PR‡ (95% CI)	N (cases) Exposed	PR‡ (95% CI)
High total cholesterol (>5.5 mmol/L)						
PFOS (total)	248 (90)	1.05 (0.95,1.16)	151 (47)	1.05 (0.91,1.22)	276 (99)	1.13 (1.02,1.25)
PFOS (branched isomers)	248 (90)	1.02 (0.90,1.16)	148 (47)	1.02 (0.83,1.24)	254 (89)	1.18 (1.04,1.33)
PFOA	248 (90)	1.14 (0.93,1.38)	151 (47)	1.00 (0.79,1.28)	276 (99)	1.30 (1.10,1.55)
PFHxS	248 (90)	1.00 (0.92,1.09)	151 (47)	1.06 (0.93,1.20)	276 (99)	1.15 (1.05,1.27)
Low HDL cholesterol^						
PFOS (total)	248 (32)	0.86 (0.66,1.13)	151 (14)	0.83 (0.53,1.29)	276 (25)	0.90 (0.63,1.29)
PFOS (branched isomers)	248 (32)	0.94 (0.71,1.24)	148 (13)	0.86 (0.53,1.38)	254 (24)	1.21 (0.85,1.73)
PFOA	248 (32)	0.80 (0.54,1.17)	151 (14)	0.97 (0.58,1.62)	276 (25)	1.01 (0.62,1.63)
PFHxS	248 (32)	0.86 (0.73,1.02)	151 (14)	1.02 (0.76,1.38)	276 (25)	1.00 (0.82,1.22)
High LDL cholesterol (>4 mmol/L)						
PFOS (total)	232 (35)	1.01 (0.80,1.27)	151 (19)	1.01 (0.80,1.29)	271 (40)	1.03 (0.86,1.23)
PFOS (branched isomers)	232 (35)	0.96 (0.74,1.25)	148 (19)	1.05 (0.81,1.37)	249 (34)	1.07 (0.87,1.30)
PFOA	232 (35)	1.10 (0.72,1.68)	151 (19)	0.91 (0.66,1.24)	271 (40)	1.36 (1.03,1.79)
PFHxS	232 (35)	0.96 (0.79,1.16)	151 (19)	1.01 (0.85,1.19)	271 (40)	1.08 (0.92,1.28)
High total:HDL cholesterol ratio (>4.5)						
PFOS (total)	248 (66)	0.94 (0.82,1.08)	151 (48)	1.05 (0.88,1.25)	276 (77)	1.02 (0.90,1.15)
PFOS (branched isomers)	248 (66)	1.03 (0.89,1.20)	148 (47)	1.14 (0.94,1.39)	254 (74)	1.07 (0.94,1.23)
PFOA	248 (66)	1.05 (0.80,1.37)	151 (48)	0.96 (0.77,1.21)	276 (77)	1.26 (1.00,1.60)
PFHxS	248 (66)	0.96 (0.85,1.07)	151 (48)	1.00 (0.88,1.15)	276 (77)	1.07 (0.96,1.19)
High triglycerides (>2 mmol/L)						
PFOS (total)	248 (85)	0.92 (0.80,1.05)	151 (65)	1.02 (0.88,1.18)	276 (93)	0.99 (0.87,1.13)
PFOS (branched isomers)	248 (85)	0.96 (0.83,1.11)	148 (63)	1.06 (0.90,1.26)	254 (91)	1.04 (0.90,1.19)
PFOA	248 (85)	1.08 (0.87,1.34)	151 (65)	1.09 (0.90,1.34)	276 (93)	1.14 (0.93,1.39)
PFHxS	248 (85)	0.93 (0.84,1.03)	151 (65)	1.04 (0.93,1.17)	276 (93)	1.01 (0.91,1.13)
High serum creatinine^						
PFOS (total)	248 (9)	0.88 (0.65,1.20)	151 (12)	1.09 (0.63,1.88)	276 (7)	1.11 (0.75,1.65)
PFOS (branched isomers)	248 (9)	0.90 (0.64,1.28)	148 (11)	1.04 (0.46,2.33)	254 (5)	0.96 (0.54,1.72)
PFOA	248 (9)	0.94 (0.44,2.01)	151 (12)	1.03 (0.39,2.74)	276 (7)	1.74 (1.31,2.31)

	Katherine, NT		Oakey, Qld		Williamtown, NSW	
	N (cases) Exposed	PR‡ (95% CI)	N (cases) Exposed	PR‡ (95% CI)	N (cases) Exposed	PR‡ (95% CI)
PFHxS	248 (9)	0.85 (0.67,1.08)	151 (12)	1.10 (0.67,1.81)	276 (7)	0.98 (0.61,1.57)
High urate (uric acid)^						
PFOS (total)	248 (19)	1.19 (0.98,1.43)	151 (9)	1.34 (0.93,1.93)	276 (22)	1.22 (0.97,1.55)
PFOS (branched isomers)	248 (19)	1.20 (0.97,1.48)	148 (8)	0.94 (0.49,1.80)	254 (19)	1.36 (1.01,1.83)#
PFOA	248 (19)	1.72 (0.98,3.02)	151 (9)	1.14 (0.42,3.09)	276 (22)	1.98 (1.24,3.14)
PFHxS	248 (19)	1.01 (0.84,1.22)	151 (9)	1.05 (0.64,1.72)	276 (22)	1.06 (0.81,1.39)
Low eGFR (<60 mL/min/1.73 m2) CKD-EPI formula						
PFOS (total)	247 (7)	0.95 (0.64,1.42)	151 (9)	1.13 (0.62,2.08)	274 (9)	1.08 (0.77,1.52)
PFOS (branched isomers)	247 (7)	0.94 (0.61,1.46)	148 (9)	1.34 (0.54,3.34)	253 (7)	0.76 (0.52,1.11)
PFOA	247 (7)	0.79 (0.28,2.20)	151 (9)	1.43 (0.33,6.29)	274 (9)	1.25 (0.81,1.92)
PFHxS	247 (7)	0.93 (0.73,1.20)	151 (9)	1.15 (0.66,2.01)	274 (9)	0.97 (0.64,1.47)
High ALT^						
PFOS (total)	225 (12)	0.97 (0.63,1.48)	150 (10)	NC	273 (12)	1.46 (1.02,2.09)
PFOS (branched isomers)	225 (12)	0.95 (0.57,1.58)	147 (9)	NC	251 (12)	1.52 (0.98,2.36)
PFOA	225 (12)	0.89 (0.59,1.33)	150 (10)	NC	273 (12)	1.11 (0.67,1.84)
PFHxS	225 (12)	0.93 (0.68,1.27)	150 (10)	NC	273 (12)	1.20 (0.79,1.81)
High AST^						
PFOS (total)	247 (10)	0.92 (0.61,1.39)	151 (8)	1.38 (0.90,2.12)	275 (4)	NC
PFOS (branched isomers)	247 (10)	0.87 (0.51,1.49)	148 (6)	1.18 (0.59,2.35)	253 (4)	NC
PFOA	247 (10)	0.77 (0.49,1.22)	151 (8)	1.53 (0.89,2.62)	275 (4)	NC
PFHxS	247 (10)	0.95 (0.66,1.37)	151 (8)	1.19 (0.83,1.70)	275 (4)	NC
High GGT^						
PFOS (total)	248 (33)	0.95 (0.79,1.13)	151 (25)	1.06 (0.81,1.38)	276 (45)	1.14 (0.92,1.40)
PFOS (branched isomers)	248 (33)	0.91 (0.73,1.15)	148 (24)	1.12 (0.78,1.60)	254 (43)	1.18 (0.93,1.49)
PFOA	248 (33)	1.06 (0.79,1.41)	151 (25)	1.23 (0.80,1.88)	276 (45)	1.34 (0.95,1.89)
PFHxS	248 (33)	0.95 (0.83,1.09)	151 (25)	0.96 (0.76,1.21)	276 (45)	1.12 (0.96,1.31)
High ALP^						
PFOS (total)	248 (11)	NC	151 (9)	1.03 (0.66,1.61)	275 (17)	1.19 (0.93,1.53)
PFOS (branched isomers)	248 (11)	NC	148 (9)	1.25 (0.74,2.13)	253 (15)	1.40 (1.05,1.86)
PFOA	248 (11)	NC	151 (9)	0.89 (0.63,1.26)	275 (17)	1.46 (0.78,2.76)
PFHxS	248 (11)	NC	151 (9)	1.10 (0.78,1.54)	275 (17)	0.98 (0.73,1.30)
Abnormal TSH^						
PFOS (total)	248 (8)	NC	151 (3)	0.56 (0.26,1.17)	275 (10)	1.23 (0.89,1.69)
PFOS (branched isomers)	248 (8)	NC	148 (3)	0.57 (0.27,1.18)	253 (7)	NC
PFOA	248 (8)	NC	151 (3)	4.47 (1.71,11.70)	275 (10)	0.84 (0.46,1.52)

	Katherine, NT		Oakey, Qld		Williamtown, NSW	
	N (cases) Exposed	PR‡ (95% CI)	N (cases) Exposed	PR‡ (95% CI)	N (cases) Exposed	PR‡ (95% CI)
PFHxS	248 (8)	NC	151 (3)	0.56 (0.39,0.78)	275 (10)	1.25 (0.93,1.69)

N: sample size; PR: prevalence ratio; NC: convergence not achieved.

‡ Adjusted for age, sex, level of education and gross household annual income. Age was modelled using a restricted cubic spline with 3 knots.

^ Reference intervals vary by sex and age.

Estimated assuming an independence (rather than exchangeable) within-cluster correlation structure and cluster-robust standard errors.

Table A6-16. Differences in mean lipid, liver, kidney and thyroid function biomarker concentrations per doubling in PFAS serum concentrations for residents and workers of PFAS Management Areas, 2016–2020. Sensitivity analysis: excluding exposed participants who have not lived in the exposed communities for at least 1 year.

	Katherine, NT		Oakey, Qld		Williamtown, NSW	
	N Exposed	Difference¶ (95% CI)	N Exposed	Difference¶ (95% CI)	N Exposed	Difference¶ (95% CI)
Total cholesterol (mmol/L)						
PFOS (total)	248	−0.00 (−0.09,0.09)	151	0.07 (−0.05,0.19)	276	0.10 (0.01,0.19)
PFOS (branched isomers)	248	−0.02 (−0.12,0.08)	148	−0.01 (−0.20,0.18)	254	0.10 (−0.01,0.20)
PFOA	248	0.13 (−0.01,0.26)	151	−0.03 (−0.29,0.23)	276	0.21 (0.07,0.35)
PFHxS	248	−0.02 (−0.10,0.06)	151	0.01 (−0.13,0.15)	276	0.10 (0.02,0.18)
HDL cholesterol (mmol/L)						
PFOS (total)	248	0.02 (−0.01,0.05)	151	−0.00 (−0.04,0.03)	276	0.03 (−0.01,0.06)
PFOS (branched isomers)	248	0.00 (−0.03,0.04)	148	−0.03 (−0.06,0.01)	254	−0.01 (−0.04,0.03)
PFOA	248	0.03 (−0.02,0.08)	151	−0.01 (−0.05,0.04)	276	0.00 (−0.05,0.06)
PFHxS	248	0.02 (−0.00,0.04)	151	−0.00 (−0.03,0.03)	276	0.00 (−0.02,0.03)
LDL cholesterol (mmol/L)						
PFOS (total)	232	0.01 (−0.08,0.10)	151	0.08 (−0.02,0.17)	271	0.06 (−0.02,0.13)
PFOS (branched isomers)	232	−0.01 (−0.11,0.09)	148	0.05 (−0.06,0.16)	249	0.05 (−0.04,0.15)
PFOA	232	0.12 (−0.01,0.25)	151	0.06 (−0.07,0.19)	271	0.14 (0.02,0.26)
PFHxS	232	−0.03 (−0.10,0.04)	151	0.02 (−0.06,0.09)	271	0.08 (0.01,0.15)
Total:HDL cholesterol ratio						
PFOS (total)	248	−0.05 (−0.15,0.05)	151	0.06 (−0.08,0.21)	276	0.01 (−0.09,0.11)
PFOS (branched isomers)	248	−0.01 (−0.13,0.11)	148	0.06 (−0.15,0.26)	254	0.10 (−0.02,0.21)
PFOA	248	−0.01 (−0.18,0.17)	151	−0.02 (−0.30,0.27)	276	0.21 (0.07,0.36)
PFHxS	248	−0.06 (−0.14,0.02)	151	0.02 (−0.14,0.17)	276	0.07 (−0.02,0.15)
Triglycerides (mmol/L)						
PFOS (total)	248	−0.07 (−0.17,0.03)	151	0.06 (−0.09,0.20)	276	0.01 (−0.10,0.11)
PFOS (branched isomers)	248	−0.04 (−0.16,0.07)	148	0.02 (−0.12,0.15)	254	0.05 (−0.07,0.17)
PFOA	248	0.01 (−0.14,0.15)	151	0.00 (−0.17,0.17)	276	0.13 (−0.01,0.27)
PFHxS	248	−0.06 (−0.13,0.02)	151	0.05 (−0.08,0.18)	276	0.03 (−0.06,0.11)
Serum creatinine (umol/L)						
PFOS (total)	248	0.33 (−1.11,1.77)	151	0.74 (−1.46,2.94)	276	0.18 (−0.85,1.22)
PFOS (branched isomers)	248	0.43 (−1.01,1.87)	148	−0.28 (−3.74,3.19)	254	−0.12 (−1.44,1.21)
PFOA	248	−0.86 (−4.59,2.87)	151	0.40 (−3.83,4.64)	276	−0.36 (−1.99,1.27)
PFHxS	248	−0.76 (−1.70,0.19)	151	0.02 (−2.40,2.44)	276	−0.24 (−1.30,0.82)
Urate (uric acid) (mmol/L)						
PFOS (total)	248	0.00 (−0.01,0.01)	151	0.00 (−0.01,0.01)	276	0.00 (−0.00,0.01)

	Katherine, NT		Oakey, Qld		Williamtown, NSW	
	N Exposed	Difference¶ (95% CI)	N Exposed	Difference¶ (95% CI)	N Exposed	Difference¶ (95% CI)
PFOS (branched isomers)	248	0.00 (−0.01,0.01)	148	−0.00 (−0.02,0.01)	254	0.01 (−0.00,0.02)
PFOA	248	0.01 (0.00,0.02)	151	0.01 (−0.01,0.02)	276	0.02 (0.01,0.03)
PFHxS	248	−0.00 (−0.01,0.00)	151	−0.00 (−0.01,0.01)	276	0.00 (−0.00,0.01)
eGFR (mL/min/1.73 m2) CKD-EPI formula						
PFOS (total)	247	−0.24 (−1.47,1.00)	151	−1.16 (−3.00,0.69)	274	−0.12 (−1.09,0.84)
PFOS (branched isomers)	247	−0.46 (−1.81,0.89)	148	−0.47 (−3.10,2.15)	253	0.02 (−1.19,1.23)
PFOA	247	0.01 (−2.69,2.71)	151	−0.93 (−4.04,2.18)	274	0.38 (−1.24,2.00)
PFHxS	247	0.69 (−0.21,1.59)	151	−0.50 (−2.35,1.35)	274	0.20 (−0.75,1.15)
ALT (U/L)						
PFOS (total)	225	−0.80 (−1.78,0.19)	150	0.49 (−0.82,1.80)	273	0.30 (−0.54,1.14)
PFOS (branched isomers)	225	−0.79 (−1.95,0.38)	147	0.65 (−0.96,2.27)	251	0.96 (−0.10,2.01)
PFOA	225	−0.37 (−1.55,0.82)	150	0.67 (−0.71,2.04)	273	0.51 (−0.66,1.67)
PFHxS	225	−0.73 (−1.52,0.05)	150	0.12 (−0.84,1.08)	273	0.30 (−0.43,1.02)
AST (U/L)						
PFOS (total)	247	−0.67 (−1.65,0.30)	151	0.79 (−0.54,2.11)	275	0.14 (−0.39,0.67)
PFOS (branched isomers)	247	−0.56 (−1.73,0.60)	148	0.38 (−0.78,1.54)	253	0.33 (−0.33,0.99)
PFOA	247	−0.17 (−1.22,0.89)	151	1.73 (0.69,2.77)	275	0.75 (−0.14,1.63)
PFHxS	247	−0.63 (−1.36,0.11)	151	0.53 (−0.42,1.48)	275	−0.13 (−0.65,0.38)
GGT (U/L)						
PFOS (total)	248	1.64 (−1.98,5.26)	151	0.44 (−2.21,3.08)	276	0.80 (−1.60,3.20)
PFOS (branched isomers)	248	1.25 (−2.81,5.31)	148	0.69 (−2.69,4.08)	254	1.04 (−1.56,3.63)
PFOA	248	1.20 (−2.30,4.70)	151	0.65 (−1.84,3.13)	276	1.40 (−1.34,4.15)
PFHxS	248	1.54 (−0.95,4.02)	151	0.16 (−1.88,2.21)	276	0.34 (−1.45,2.13)
ALP (U/L)						
PFOS (total)	248	0.13 (−2.01,2.28)	151	−0.85 (−2.86,1.15)	275	−1.03 (−2.78,0.73)
PFOS (branched isomers)	248	−0.11 (−2.51,2.29)	148	0.87 (−1.54,3.29)	253	0.91 (−1.17,2.99)
PFOA	248	1.77 (−0.94,4.48)	151	−0.72 (−3.37,1.92)	275	1.25 (−1.97,4.48)
PFHxS	248	−0.07 (−1.88,1.75)	151	0.12 (−1.59,1.82)	275	−0.86 (−2.55,0.83)
Serum albumin (g/L)						
PFOS (total)	248	−0.05 (−0.33,0.22)	151	0.41 (0.09,0.72)	276	0.08 (−0.15,0.30)
PFOS (branched isomers)	248	−0.04 (−0.33,0.26)	148	0.38 (−0.01,0.77)	254	0.12 (−0.17,0.40)
PFOA	248	0.32 (−0.17,0.81)	151	0.45 (−0.01,0.91)	276	0.27 (−0.10,0.64)
PFHxS	248	−0.13 (−0.35,0.10)	151	0.19 (−0.05,0.44)	276	0.06 (−0.16,0.27)
Total protein (g/L)						
PFOS (total)	248	−0.03 (−0.41,0.35)	151	0.63 (0.09,1.17)	276	−0.09 (−0.46,0.29)
PFOS (branched isomers)	248	0.03 (−0.41,0.46)	148	0.43 (−0.17,1.03)	254	0.06 (−0.41,0.53)

	Katherine, NT		Oakey, Qld		Williamtown, NSW	
	N Exposed	Difference¶ (95% CI)	N Exposed	Difference¶ (95% CI)	N Exposed	Difference¶ (95% CI)
PFOA	248	0.48 (−0.11,1.06)	151	0.45 (−0.21,1.12)	276	0.40 (−0.12,0.92)
PFHxS	248	−0.18 (−0.51,0.15)	151	0.37 (−0.04,0.78)	276	0.02 (−0.33,0.38)
TSH (mIU/L)						
PFOS (total)	248	−0.01 (−0.08,0.05)	151	−0.02 (−0.11,0.07)	275	0.01 (−0.05,0.06)
PFOS (branched isomers)	248	−0.01 (−0.09,0.06)	148	0.02 (−0.08,0.11)	253	−0.00 (−0.08,0.07)
PFOA	248	0.09 (−0.02,0.21)	151	0.13 (−0.01,0.27)	275	0.04 (−0.06,0.14)
PFHxS	248	−0.00 (−0.05,0.05)	151	−0.01 (−0.08,0.06)	275	−0.02 (−0.08,0.03)
Free T3 (pmol/L)						
PFOS (total)	248	−0.01 (−0.05,0.03)	151	0.01 (−0.05,0.08)	275	−0.01 (−0.05,0.03)
PFOS (branched isomers)	248	0.01 (−0.04,0.06)	148	0.01 (−0.07,0.09)	253	0.04 (−0.02,0.09)
PFOA	248	0.01 (−0.05,0.07)	151	−0.02 (−0.10,0.05)	275	−0.01 (−0.08,0.07)
PFHxS	248	−0.00 (−0.03,0.03)	151	−0.01 (−0.07,0.05)	275	−0.01 (−0.04,0.03)
Free T4 (pmol/L)						
PFOS (total)	247	−0.00 (−0.11,0.10)	151	0.07 (−0.06,0.20)	275	−0.01 (−0.14,0.12)
PFOS (branched isomers)	247	0.04 (−0.08,0.16)	148	0.10 (−0.04,0.24)	253	0.03 (−0.12,0.18)
PFOA	247	0.04 (−0.13,0.22)	151	0.07 (−0.10,0.23)	275	−0.02 (−0.23,0.19)
PFHxS	247	−0.03 (−0.11,0.06)	151	0.06 (−0.05,0.16)	275	0.07 (−0.04,0.19)

N: sample size; NC: convergence not achieved.

¶ Adjusted for age, sex, level of education and gross household annual income. Age was modelled using a restricted cubic spline with 3 knots.

Estimated assuming an independence (rather than exchangeable) within-cluster correlation structure and cluster-robust standard errors.

Biochemical marker sensitivity analysis 8: PFAS serum concentrations below the limit of quantification imputed using multiple imputation by chained equations, rather than using a single plug-in value

Table A6-17. Adjusted prevalence ratios of adverse lipid, liver, kidney and thyroid function biomarker concentrations per doubling in PFAS serum concentrations for residents and workers of PFAS Management Areas, 2016–2020. Sensitivity analysis: PFAS serum concentrations below the limit of quantification imputed using multiple imputation by chained equations, rather than using a single plug-in value of the limit/sqrt(2).

	Katherine, NT		Oakey, Qld		Williamtown, NSW	
	N (cases) Exposed	PR‡ (95% CI)	N (cases) Exposed	PR‡ (95% CI)	N (cases) Exposed	PR‡ (95% CI)
High total cholesterol (>5.5 mmol/L)						
PFOS (total)	250 (91)	1.04 (0.94,1.16)	153 (49)	1.06 (0.92,1.22)	277 (99)	1.13 (1.02,1.26)
PFOS (branched isomers)	250 (91)	1.02 (0.90,1.15)	150 (49)	1.03 (0.85,1.25)	255 (89)	1.18 (1.05,1.33)
PFOA	250 (91)	1.14 (0.94,1.39)	153 (49)	1.04 (0.81,1.33)	277 (99)	1.31 (1.10,1.56)
PFHxS	250 (91)	1.00 (0.92,1.09)	153 (49)	1.06 (0.93,1.20)	277 (99)	1.15 (1.05,1.27)
Low HDL cholesterol^						
PFOS (total)	250 (32)	0.87 (0.66,1.13)	153 (14)	0.82 (0.53,1.29)	277 (25)	0.90 (0.62,1.30)
PFOS (branched isomers)	250 (32)	0.94 (0.72,1.23)	150 (13)	0.86 (0.54,1.37)	255 (24)	1.21 (0.85,1.72)
PFOA	250 (32)	0.79 (0.53,1.19)	153 (14)	0.96 (0.57,1.60)	277 (25)	1.01 (0.62,1.64)
PFHxS	250 (32)	0.86 (0.73,1.02)	153 (14)	1.02 (0.75,1.38)	277 (25)	1.00 (0.82,1.23)
High LDL cholesterol (>4 mmol/L)						
PFOS (total)	234 (36)	0.99 (0.78,1.25)	153 (19)	1.01 (0.79,1.28)	272 (40)	1.03 (0.86,1.23)
PFOS (branched isomers)	234 (36)	0.94 (0.73,1.21)	150 (19)	1.05 (0.82,1.36)	250 (34)	1.08 (0.89,1.30)
PFOA	234 (36)	1.11 (0.74,1.68)	153 (19)	0.89 (0.65,1.23)	272 (40)	1.36 (1.03,1.80)
PFHxS	234 (36)	0.95 (0.79,1.15)	153 (19)	1.01 (0.85,1.19)	272 (40)	1.09 (0.92,1.28)
High total:HDL cholesterol ratio (>4.5)						
PFOS (total)	250 (67)	0.94 (0.82,1.07)	153 (48)	1.05 (0.88,1.25)	277 (77)	1.02 (0.90,1.16)
PFOS (branched isomers)	250 (67)	1.02 (0.88,1.18)	150 (47)	1.13 (0.94,1.38)	255 (74)	1.08 (0.95,1.23)
PFOA	250 (67)	1.05 (0.80,1.37)	153 (48)	0.95 (0.75,1.20)	277 (77)	1.26 (1.00,1.60)
PFHxS	250 (67)	0.95 (0.85,1.06)	153 (48)	1.00 (0.88,1.15)	277 (77)	1.07 (0.96,1.19)
High triglycerides (>2 mmol/L)						
PFOS (total)	250 (86)	0.92 (0.80,1.05)	153 (65)	1.02 (0.88,1.18)	277 (93)	1.00 (0.87,1.13)
PFOS (branched isomers)	250 (86)	0.96 (0.84,1.10)	150 (63)	1.06 (0.89,1.25)	255 (91)	1.04 (0.91,1.19)
PFOA	250 (86)	1.08 (0.87,1.34)	153 (65)	1.08 (0.88,1.32)	277 (93)	1.14 (0.93,1.39)
PFHxS	250 (86)	0.93 (0.84,1.03)	153 (65)	1.04 (0.93,1.17)	277 (93)	1.02 (0.92,1.13)
High serum creatinine^						
PFOS (total)	250 (9)	0.89 (0.65,1.20)	153 (12)	1.08 (0.63,1.88)	277 (7)	1.12 (0.75,1.66)
PFOS (branched isomers)	250 (9)	0.92 (0.67,1.27)	150 (11)	1.00 (0.45,2.25)	255 (5)	1.00 (0.59,1.68)
PFOA	250 (9)	0.93 (0.42,2.05)	153 (12)	1.04 (0.39,2.76)	277 (7)	1.74 (1.31,2.32)

	Katherine, NT		Oakey, Qld		Williamtown, NSW	
	N (cases) Exposed	PR‡ (95% CI)	N (cases) Exposed	PR‡ (95% CI)	N (cases) Exposed	PR‡ (95% CI)
PFHxS	250 (9)	0.85 (0.68,1.07)	153 (12)	1.10 (0.67,1.81)	277 (7)	0.99 (0.62,1.57)
High urate (uric acid)^						
PFOS (total)	250 (19)	1.19 (0.98,1.44)	153 (9)	1.34 (0.92,1.93)	277 (22)	1.23 (0.97,1.56)
PFOS (branched isomers)	250 (19)	1.20 (0.98,1.48)	150 (8)	0.93 (0.50,1.75)	255 (19)	1.36 (1.02,1.81)#
PFOA	250 (19)	1.72 (0.98,3.03)	153 (9)	1.15 (0.43,3.06)	277 (22)	1.99 (1.25,3.17)
PFHxS	250 (19)	1.01 (0.84,1.22)	153 (9)	1.05 (0.64,1.72)	277 (22)	1.06 (0.82,1.39)
Low eGFR (<60 mL/min/1.73 m2) CKD-EPI formula						
PFOS (total)	249 (7)	0.96 (0.64,1.43)	153 (9)	1.13 (0.61,2.08)	275 (9)	1.09 (0.77,1.53)
PFOS (branched isomers)	249 (7)	0.97 (0.66,1.44)	150 (9)	1.31 (0.52,3.30)	254 (7)	0.80 (0.57,1.13)
PFOA	249 (7)	0.78 (0.27,2.27)	153 (9)	1.47 (0.34,6.31)	275 (9)	1.25 (0.81,1.93)
PFHxS	249 (7)	0.93 (0.73,1.20)	153 (9)	1.15 (0.66,2.01)	275 (9)	0.97 (0.64,1.47)
High ALT^						
PFOS (total)	227 (12)	0.97 (0.63,1.48)	152 (10)	NC	274 (12)	1.46 (1.02,2.09)
PFOS (branched isomers)	227 (12)	0.95 (0.58,1.54)	149 (9)	NC	252 (12)	1.51 (0.98,2.33)
PFOA	227 (12)	0.88 (0.58,1.34)	152 (10)	NC	274 (12)	1.11 (0.67,1.85)
PFHxS	227 (12)	0.93 (0.69,1.27)	152 (10)	NC	274 (12)	1.20 (0.80,1.81)
High AST^						
PFOS (total)	249 (10)	0.92 (0.61,1.39)	153 (8)	1.39 (0.90,2.14)	276 (4)	NC
PFOS (branched isomers)	249 (10)	0.88 (0.54,1.45)	150 (6)	1.16 (0.57,2.38)	254 (4)	NC
PFOA	249 (10)	0.76 (0.47,1.22)	153 (8)	1.52 (0.88,2.63)	276 (4)	NC
PFHxS	249 (10)	0.95 (0.66,1.37)	153 (8)	1.19 (0.83,1.71)	276 (4)	NC
High GGT^						
PFOS (total)	250 (33)	0.95 (0.79,1.13)	153 (26)	1.08 (0.84,1.40)	277 (45)	1.14 (0.92,1.41)
PFOS (branched isomers)	250 (33)	0.94 (0.76,1.15)	150 (25)	1.16 (0.83,1.62)	255 (43)	1.19 (0.94,1.50)
PFOA	250 (33)	1.05 (0.79,1.41)	153 (26)	1.30 (0.84,2.00)	277 (45)	1.35 (0.95,1.90)
PFHxS	250 (33)	0.95 (0.83,1.09)	153 (26)	0.98 (0.78,1.22)	277 (45)	1.12 (0.96,1.31)
High ALP^						
PFOS (total)	250 (11)	NC	153 (9)	1.02 (0.65,1.61)	276 (17)	1.20 (0.93,1.53)
PFOS (branched isomers)	250 (11)	NC	150 (9)	1.22 (0.71,2.09)	254 (15)	1.39 (1.05,1.84)
PFOA	250 (11)	NC	153 (9)	0.88 (0.62,1.25)	276 (17)	1.47 (0.78,2.77)
PFHxS	250 (11)	NC	153 (9)	1.10 (0.78,1.54)	276 (17)	0.99 (0.75,1.30)
Abnormal TSH^						
PFOS (total)	250 (8)	NC	153 (3)	0.55 (0.26,1.16)	276 (10)	1.23 (0.89,1.69)
PFOS (branched isomers)	250 (8)	NC	150 (3)	0.59 (0.30,1.18)	254 (7)	NC
PFOA	250 (8)	NC	153 (3)	4.48 (1.68,11.93)	276 (10)	0.84 (0.46,1.53)

	Katherine, NT		Oakey, Qld		Williamtown, NSW	
	N (cases) Exposed	PR‡ (95% CI)	N (cases) Exposed	PR‡ (95% CI)	N (cases) Exposed	PR‡ (95% CI)
PFHxS	250 (8)	NC	153 (3)	0.56 (0.39,0.81)	276 (10)	1.26 (0.93,1.70)

Among survey respondents, detection rates were 99.5–100% for PFOS, 97.8-99.5% for PFOA and 93.6-96.2% for PFHxS.

N: sample size; PR: prevalence ratio; NC: convergence not achieved.

‡ Adjusted for age, sex, level of education and gross household annual income. Age was modelled using a restricted cubic spline with 3 knots.

^ Reference intervals vary by sex and age.

Estimated assuming an independence (rather than exchangeable) within-cluster correlation structure and cluster-robust standard errors.

Table A6-18. Differences in mean lipid, liver, kidney and thyroid function biomarker concentrations per doubling in PFAS serum concentrations for residents and workers of PFAS Management Areas, 2016–2020. Sensitivity analysis: PFAS serum concentrations below the limit of quantification imputed using multiple imputation by chained equations, rather than using a single plug-in value of the limit/sqrt(2).

	Katherine, NT		Oakey, Qld		Williamtown, NSW	
	N Exposed	Difference¶ (95% CI)	N Exposed	Difference¶ (95% CI)	N Exposed	Difference¶ (95% CI)
Total cholesterol (mmol/L)						
PFOS (total)	250	−0.01 (−0.10,0.09)	153	0.07 (−0.05,0.19)	277	0.11 (0.02,0.20)
PFOS (branched isomers)	250	−0.03 (−0.12,0.07)	150	−0.00 (−0.19,0.18)	255	0.10 (0.00,0.20)
PFOA	250	0.13 (−0.01,0.27)	153	−0.01 (−0.27,0.25)	277	0.21 (0.07,0.35)
PFHxS	250	−0.02 (−0.10,0.05)	153	0.01 (−0.13,0.15)	277	0.10 (0.02,0.18)
HDL cholesterol (mmol/L)						
PFOS (total)	250	0.02 (−0.01,0.05)	153	−0.00 (−0.04,0.04)	277	0.03 (−0.01,0.07)
PFOS (branched isomers)	250	0.00 (−0.03,0.04)	150	−0.02 (−0.06,0.01)	255	−0.01 (−0.04,0.03)
PFOA	250	0.03 (−0.02,0.08)	153	−0.00 (−0.05,0.05)	277	0.00 (−0.05,0.06)
PFHxS	250	0.02 (−0.00,0.04)	153	−0.00 (−0.03,0.03)	277	0.01 (−0.02,0.03)
LDL cholesterol (mmol/L)						
PFOS (total)	234	0.01 (−0.08,0.09)	153	0.08 (−0.01,0.17)	272	0.06 (−0.02,0.13)
PFOS (branched isomers)	234	−0.02 (−0.11,0.08)	150	0.05 (−0.05,0.16)	250	0.05 (−0.03,0.14)
PFOA	234	0.12 (−0.01,0.25)	153	0.07 (−0.06,0.20)	272	0.14 (0.02,0.26)
PFHxS	234	−0.03 (−0.11,0.04)	153	0.02 (−0.05,0.10)	272	0.08 (0.01,0.14)
Total:HDL cholesterol ratio						
PFOS (total)	250	−0.05 (−0.16,0.05)	153	0.06 (−0.08,0.20)	277	0.01 (−0.09,0.11)
PFOS (branched isomers)	250	−0.01 (−0.13,0.10)	150	0.05 (−0.14,0.25)	255	0.10 (−0.01,0.20)
PFOA	250	−0.00 (−0.18,0.18)	153	−0.02 (−0.30,0.26)	277	0.21 (0.07,0.36)
PFHxS	250	−0.06 (−0.14,0.02)	153	0.02 (−0.13,0.17)	277	0.07 (−0.02,0.15)
Triglycerides (mmol/L)						
PFOS (total)	250	−0.08 (−0.18,0.02)	153	0.05 (−0.09,0.19)	277	0.01 (−0.10,0.12)
PFOS (branched isomers)	250	−0.05 (−0.16,0.06)	150	0.01 (−0.12,0.14)	255	0.05 (−0.06,0.16)
PFOA	250	0.01 (−0.13,0.15)	153	−0.01 (−0.18,0.16)	277	0.13 (−0.01,0.27)
PFHxS	250	−0.06 (−0.14,0.01)	153	0.05 (−0.08,0.18)	277	0.03 (−0.05,0.11)
Serum creatinine (umol/L)						
PFOS (total)	250	0.38 (−1.05,1.82)	153	0.66 (−1.54,2.86)	277	0.16 (−0.88,1.21)
PFOS (branched isomers)	250	0.53 (−0.82,1.87)	150	−0.36 (−3.69,2.98)	255	−0.11 (−1.37,1.15)
PFOA	250	−0.92 (−4.73,2.88)	153	0.33 (−3.83,4.50)	277	−0.37 (−2.00,1.26)
PFHxS	250	−0.72 (−1.66,0.22)	153	−0.01 (−2.40,2.38)	277	−0.28 (−1.33,0.77)
Urate (uric acid) (mmol/L)						
PFOS (total)	250	−0.00 (−0.01,0.01)	153	0.00 (−0.01,0.01)	277	0.00 (−0.00,0.01)

	Katherine, NT		Oakey, Qld		Williamtown, NSW	
	N Exposed	Difference¶ (95% CI)	N Exposed	Difference¶ (95% CI)	N Exposed	Difference¶ (95% CI)
PFOS (branched isomers)	250	0.00 (−0.01,0.01)	150	−0.00 (−0.01,0.01)	255	0.01 (−0.00,0.02)
PFOA	250	0.01 (0.00,0.02)	153	0.01 (−0.01,0.02)	277	0.02 (0.01,0.03)
PFHxS	250	−0.00 (−0.01,0.00)	153	−0.00 (−0.01,0.01)	277	0.00 (−0.00,0.01)
eGFR (mL/min/1.73 m2) CKD-EPI formula						
PFOS (total)	249	−0.28 (−1.52,0.95)	153	−1.07 (−2.92,0.77)	275	−0.09 (−1.07,0.88)
PFOS (branched isomers)	249	−0.56 (−1.82,0.71)	150	−0.38 (−2.91,2.16)	254	0.02 (−1.15,1.19)
PFOA	249	0.05 (−2.70,2.81)	153	−0.81 (−3.90,2.27)	275	0.39 (−1.23,2.01)
PFHxS	249	0.66 (−0.24,1.55)	153	−0.47 (−2.31,1.37)	275	0.25 (−0.69,1.20)
ALT (U/L)						
PFOS (total)	227	−0.77 (−1.75,0.22)	152	0.43 (−0.87,1.74)	274	0.31 (−0.54,1.16)
PFOS (branched isomers)	227	−0.70 (−1.81,0.40)	149	0.55 (−1.01,2.11)	252	0.97 (−0.01,1.94)
PFOA	227	−0.38 (−1.58,0.82)	152	0.55 (−0.84,1.94)	274	0.51 (−0.65,1.68)
PFHxS	227	−0.73 (−1.51,0.05)	152	0.10 (−0.86,1.05)	274	0.31 (−0.41,1.02)
AST (U/L)						
PFOS (total)	249	−0.69 (−1.66,0.28)	153	0.75 (−0.56,2.06)	276	0.13 (−0.40,0.67)
PFOS (branched isomers)	249	−0.53 (−1.64,0.58)	150	0.37 (−0.76,1.50)	254	0.34 (−0.28,0.96)
PFOA	249	−0.17 (−1.25,0.90)	153	1.66 (0.61,2.70)	276	0.74 (−0.14,1.63)
PFHxS	249	−0.64 (−1.37,0.10)	153	0.51 (−0.44,1.45)	276	−0.13 (−0.64,0.38)
GGT (U/L)						
PFOS (total)	250	1.63 (−1.98,5.25)	153	0.55 (−2.09,3.19)	277	0.84 (−1.58,3.25)
PFOS (branched isomers)	250	1.37 (−2.50,5.24)	150	0.90 (−2.26,4.06)	255	1.15 (−1.25,3.55)
PFOA	250	1.17 (−2.36,4.71)	153	0.84 (−1.69,3.37)	277	1.42 (−1.33,4.16)
PFHxS	250	1.52 (−0.95,3.99)	153	0.25 (−1.78,2.28)	277	0.40 (−1.37,2.18)
ALP (U/L)						
PFOS (total)	250	0.15 (−1.99,2.29)	153	−0.91 (−2.90,1.08)	276	−1.03 (−2.78,0.72)
PFOS (branched isomers)	250	0.08 (−2.21,2.38)	150	0.80 (−1.50,3.11)	254	0.87 (−1.10,2.84)
PFOA	250	1.79 (−0.95,4.53)	153	−0.88 (−3.54,1.79)	276	1.24 (−1.99,4.47)
PFHxS	250	−0.03 (−1.85,1.78)	153	0.12 (−1.56,1.80)	276	−0.85 (−2.53,0.83)
Serum albumin (g/L)						
PFOS (total)	250	−0.06 (−0.33,0.21)	153	0.42 (0.10,0.73)	277	0.08 (−0.14,0.31)
PFOS (branched isomers)	250	−0.04 (−0.31,0.24)	150	0.37 (−0.01,0.75)	255	0.13 (−0.14,0.40)
PFOA	250	0.33 (−0.16,0.83)	153	0.47 (0.01,0.93)	277	0.27 (−0.09,0.64)
PFHxS	250	−0.13 (−0.35,0.09)	153	0.18 (−0.06,0.43)	277	0.06 (−0.15,0.27)
Total protein (g/L)						
PFOS (total)	250	−0.05 (−0.43,0.34)	153	0.64 (0.10,1.17)	277	−0.07 (−0.45,0.31)
PFOS (branched isomers)	250	0.02 (−0.40,0.44)	150	0.44 (−0.16,1.04)	255	0.09 (−0.35,0.53)

	Katherine, NT		Oakey, Qld		Williamtown, NSW	
	N Exposed	Difference¶ (95% CI)	N Exposed	Difference¶ (95% CI)	N Exposed	Difference¶ (95% CI)
PFOA	250	0.49 (−0.11,1.09)	153	0.47 (−0.21,1.14)	277	0.40 (−0.12,0.92)
PFHxS	250	−0.19 (−0.52,0.14)	153	0.37 (−0.04,0.78)	277	0.03 (−0.32,0.39)
TSH (mIU/L)						
PFOS (total)	250	−0.01 (−0.07,0.05)	153	−0.02 (−0.11,0.07)	276	0.01 (−0.05,0.07)
PFOS (branched isomers)	250	−0.00 (−0.07,0.07)	150	0.02 (−0.08,0.11)	254	0.00 (−0.07,0.07)
PFOA	250	0.10 (−0.02,0.21)	153	0.13 (−0.01,0.27)	276	0.04 (−0.06,0.14)
PFHxS	250	−0.00 (−0.05,0.05)	153	−0.01 (−0.08,0.06)	276	−0.02 (−0.08,0.03)
Free T3 (pmol/L)						
PFOS (total)	250	−0.01 (−0.05,0.02)	153	0.01 (−0.05,0.08)	276	−0.01 (−0.05,0.03)
PFOS (branched isomers)	250	0.01 (−0.04,0.06)	150	0.01 (−0.07,0.08)	254	0.03 (−0.02,0.08)
PFOA	250	0.01 (−0.05,0.07)	153	−0.02 (−0.10,0.06)	276	−0.01 (−0.08,0.07)
PFHxS	250	−0.00 (−0.03,0.03)	153	−0.01 (−0.07,0.05)	276	−0.00 (−0.04,0.03)
Free T4 (pmol/L)						
PFOS (total)	249	−0.00 (−0.10,0.10)	153	0.08 (−0.05,0.21)	276	−0.01 (−0.14,0.12)
PFOS (branched isomers)	249	0.04 (−0.07,0.16)	150	0.10 (−0.03,0.24)	254	0.03 (−0.11,0.18)
PFOA	249	0.05 (−0.13,0.22)	153	0.08 (−0.08,0.25)	276	−0.02 (−0.23,0.19)
PFHxS	249	−0.02 (−0.11,0.06)	153	0.06 (−0.05,0.16)	276	0.08 (−0.03,0.19)

N: sample size; NC: convergence not achieved.

¶ Adjusted for age, sex, level of education and gross household annual income. Age was modelled using a restricted cubic spline with 3 knots.

Estimated assuming an independence (rather than exchangeable) within-cluster correlation structure and cluster-robust standard errors.

Biochemical marker sensitivity analysis 9: missing values in confounding variables imputed using multiple imputation by chained equations

Table A6-19. Adjusted prevalence ratios of adverse lipid, liver, kidney and thyroid function biomarker concentrations per doubling in PFAS serum concentrations for residents and workers of PFAS Management Areas, 2016–2020. Sensitivity analysis: missing values in confounding variables imputed using multiple imputation by chained equations.

	Katherine, NT		Oakey, Qld		Williamtown, NSW	
	N (cases) Exposed	PR‡ (95% CI)	N (cases) Exposed	PR‡ (95% CI)	N (cases) Exposed	PR‡ (95% CI)
High total cholesterol (>5.5 mmol/L)						
PFOS (total)	354 (124)	1.04 (0.95,1.15)	205 (66)	1.08 (0.95,1.22)	396 (140)	1.06 (0.97,1.15)
PFOS (branched isomers)	353 (123)	1.05 (0.94,1.18)	200 (65)	1.08 (0.92,1.26)	363 (126)	1.13 (1.02,1.25)
PFOA	354 (124)	1.20 (1.01,1.42)	205 (66)	1.00 (0.81,1.24)	396 (140)	1.31 (1.13,1.53)
PFHxS	354 (124)	1.02 (0.94,1.10)	205 (66)	1.07 (0.96,1.20)	396 (140)	1.09 (1.00,1.17)
Low HDL cholesterol^						
PFOS (total)	354 (38)	0.91 (0.70,1.18)	205 (19)	0.84 (0.60,1.17)	396 (32)	0.79 (0.62,1.02)
PFOS (branched isomers)	353 (38)	0.96 (0.75,1.24)	200 (18)	0.85 (0.61,1.18)	363 (31)	0.89 (0.65,1.22)
PFOA	354 (38)	0.79 (0.54,1.14)	205 (19)	1.03 (0.64,1.66)	396 (32)	0.80 (0.54,1.20)
PFHxS	354 (38)	0.91 (0.77,1.08)	205 (19)	0.96 (0.76,1.21)	396 (32)	0.89 (0.75,1.05)
High LDL cholesterol (>4 mmol/L)						
PFOS (total)	335 (50)	0.99 (0.82,1.19)	205 (25)	1.01 (0.83,1.24)	389 (55)	1.01 (0.87,1.17)
PFOS (branched isomers)	334 (49)	0.98 (0.78,1.23)	200 (24)	1.01 (0.82,1.25)	356 (46)	1.06 (0.89,1.27)
PFOA	335 (50)	1.31 (0.94,1.81)	205 (25)	0.89 (0.66,1.20)	389 (55)	1.39 (1.08,1.78)
PFHxS	335 (50)	0.97 (0.83,1.13)	205 (25)	1.01 (0.88,1.16)	389 (55)	1.05 (0.91,1.20)
High total:HDL cholesterol ratio (>4.5)						
PFOS (total)	354 (87)	0.97 (0.85,1.11)	205 (60)	1.05 (0.90,1.21)	396 (106)	0.97 (0.87,1.08)
PFOS (branched isomers)	353 (86)	1.03 (0.89,1.19)	200 (58)	1.10 (0.93,1.29)	363 (100)	1.01 (0.89,1.15)
PFOA	354 (87)	1.10 (0.86,1.39)	205 (60)	0.95 (0.77,1.18)	396 (106)	1.15 (0.94,1.40)
PFHxS	354 (87)	0.97 (0.87,1.08)	205 (60)	1.00 (0.89,1.13)	396 (106)	1.01 (0.92,1.11)
High triglycerides (>2 mmol/L)						
PFOS (total)	353 (109)	0.93 (0.83,1.05)	205 (89)	1.06 (0.96,1.18)	396 (139)	0.95 (0.86,1.06)
PFOS (branched isomers)	352 (109)	0.98 (0.85,1.11)	200 (86)	1.07 (0.94,1.22)	363 (132)	0.97 (0.86,1.10)
PFOA	353 (109)	1.09 (0.90,1.32)	205 (89)	1.04 (0.87,1.24)	396 (139)	1.02 (0.86,1.20)
PFHxS	353 (109)	0.92 (0.83,1.01)	205 (89)	1.05 (0.96,1.15)	396 (139)	0.96 (0.88,1.04)
High serum creatinine^						
PFOS (total)	354 (10)	0.96 (0.71,1.32)	205 (14)	0.97 (0.65,1.46)#	396 (10)	1.45 (1.06,2.00)
PFOS (branched isomers)	353 (10)	0.99 (0.72,1.38)	200 (13)	0.92 (0.51,1.64)#	363 (8)	1.08 (0.73,1.60)
PFOA	354 (10)	1.12 (0.51,2.47)	205 (14)	0.96 (0.40,2.31)#	396 (10)	1.31 (0.72,2.37)

	Katherine, NT		Oakey, Qld		Williamtown, NSW	
	N (cases) Exposed	PR‡ (95% CI)	N (cases) Exposed	PR‡ (95% CI)	N (cases) Exposed	PR‡ (95% CI)
PFHxS	354 (10)	0.91 (0.70,1.18)	205 (14)	1.01 (0.69,1.49)#	396 (10)	1.21 (0.76,1.94)
High urate (uric acid)^						
PFOS (total)	354 (28)	1.23 (1.05,1.44)	205 (12)	1.18 (0.91,1.53)	396 (33)	1.06 (0.87,1.29)
PFOS (branched isomers)	353 (28)	1.23 (1.00,1.51)	200 (11)	0.95 (0.63,1.44)	363 (27)	1.11 (0.83,1.49)
PFOA	354 (28)	1.73 (1.13,2.65)	205 (12)	1.15 (0.49,2.68)	396 (33)	1.50 (1.02,2.20)
PFHxS	354 (28)	1.10 (0.94,1.28)	205 (12)	0.97 (0.68,1.40)	396 (33)	1.01 (0.82,1.24)
Low eGFR (<60 mL/min/1.73 m2) CKD-EPI formula						
PFOS (total)	350 (9)	1.05 (0.76,1.44)	204 (10)	1.00 (0.64,1.59)	393 (12)	1.36 (1.01,1.84)
PFOS (branched isomers)	349 (9)	0.98 (0.59,1.63)	199 (10)	1.11 (0.58,2.12)	361 (10)	0.93 (0.66,1.31)
PFOA	350 (9)	0.97 (0.43,2.15)	204 (10)	1.18 (0.32,4.38)	393 (12)	1.06 (0.66,1.72)
PFHxS	350 (9)	1.02 (0.82,1.27)	204 (10)	1.07 (0.70,1.64)	393 (12)	1.16 (0.75,1.78)
High ALT^						
PFOS (total)	322 (17)	0.92 (0.63,1.35)#	203 (11)	NC	388 (21)	1.20 (0.93,1.54)
PFOS (branched isomers)	321 (17)	0.87 (0.56,1.36)#	198 (10)	NC	355 (21)	1.17 (0.83,1.66)
PFOA	322 (17)	0.80 (0.56,1.14)#	203 (11)	NC	388 (21)	0.90 (0.61,1.32)
PFHxS	322 (17)	0.92 (0.68,1.24)	203 (11)	NC	388 (21)	1.01 (0.74,1.37)
High AST^						
PFOS (total)	351 (11)	0.85 (0.56,1.30)	205 (9)	1.14 (0.83,1.57)	395 (8)	0.75 (0.56,1.00)
PFOS (branched isomers)	350 (11)	0.82 (0.48,1.42)	200 (7)	1.03 (0.63,1.68)	362 (8)	0.76 (0.46,1.26)
PFOA	351 (11)	0.71 (0.46,1.10)	205 (9)	1.52 (0.88,2.63)	395 (8)	0.81 (0.42,1.55)
PFHxS	351 (11)	0.87 (0.59,1.29)	205 (9)	1.11 (0.82,1.51)	395 (8)	0.70 (0.48,1.03)
High GGT^						
PFOS (total)	354 (50)	1.04 (0.90,1.20)	205 (39)	1.09 (0.92,1.28)	396 (67)	1.19 (1.03,1.38)
PFOS (branched isomers)	353 (50)	0.98 (0.80,1.20)	200 (37)	1.11 (0.87,1.42)	363 (64)	1.11 (0.92,1.36)
PFOA	354 (50)	1.00 (0.78,1.28)	205 (39)	1.40 (0.95,2.05)	396 (67)	1.31 (0.99,1.72)
PFHxS	354 (50)	1.01 (0.89,1.14)	205 (39)	0.90 (0.75,1.07)	396 (67)	1.14 (1.00,1.30)
High ALP^						
PFOS (total)	354 (18)	1.19 (0.89,1.61)#	205 (10)	0.85 (0.59,1.22)	395 (25)	1.01 (0.83,1.24)
PFOS (branched isomers)	353 (18)	1.29 (0.87,1.91)#	200 (10)	0.99 (0.64,1.55)	362 (23)	1.14 (0.86,1.51)
PFOA	354 (18)	1.11 (0.70,1.78)#	205 (10)	0.82 (0.57,1.16)	395 (25)	1.18 (0.69,2.03)
PFHxS	354 (18)	1.25 (0.98,1.60)#	205 (10)	0.94 (0.70,1.26)	395 (25)	0.89 (0.71,1.12)
Abnormal TSH^						
PFOS (total)	353 (11)	1.31 (1.01,1.71)	205 (3)	0.58 (0.27,1.23)	393 (15)	1.04 (0.76,1.42)
PFOS (branched isomers)	352 (11)	NC	200 (3)	0.59 (0.30,1.17)	360 (11)	1.12 (0.73,1.72)
PFOA	353 (11)	NC	205 (3)	4.70 (1.22,18.09)	393 (15)	0.70 (0.44,1.10)

	Katherine, NT		Oakey, Qld		Williamtown, NSW	
	N (cases) Exposed	PR‡ (95% CI)	N (cases) Exposed	PR‡ (95% CI)	N (cases) Exposed	PR‡ (95% CI)
PFHxS	353 (11)	NC	205 (3)	0.60 (0.42,0.86)	393 (15)	1.14 (0.90,1.46)

N: sample size; PR: prevalence ratio; NC: convergence not achieved.

‡ Adjusted for age, sex, level of education and gross household annual income. Age was modelled using a restricted cubic spline with 3 knots.

^ Reference intervals vary by sex and age.

Estimated assuming an independence (rather than exchangeable) within-cluster correlation structure and cluster-robust standard errors.

Table A6-20. Differences in mean lipid, liver, kidney and thyroid function biomarker concentrations per doubling in PFAS serum concentrations for residents and workers of PFAS Management Areas, 2016–2020. Sensitivity analysis: missing values in confounding variables imputed using multiple imputation by chained equations.

	Katherine, NT		Oakey, Qld		Williamtown, NSW	
	N Exposed	Difference[¶] (95% CI)	N Exposed	Difference[¶] (95% CI)	N Exposed	Difference[¶] (95% CI)
Total cholesterol (mmol/L)						
PFOS (total)	354	0.02 (−0.06,0.09)	205	0.06 (−0.04,0.16)	396	0.08 (0.00,0.15)
PFOS (branched isomers)	353	0.01 (−0.08,0.10)	200	0.00 (−0.14,0.15)	363	0.09 (0.00,0.18)
PFOA	354	0.17 (0.06,0.28)	205	−0.03 (−0.26,0.20)	396	0.23 (0.12,0.35)
PFHxS	354	−0.01 (−0.07,0.06)	205	0.02 (−0.09,0.13)	396	0.07 (0.01,0.14)
HDL cholesterol (mmol/L)						
PFOS (total)	354	0.02 (−0.00,0.05)	205	−0.01 (−0.04,0.02)	396	0.02 (−0.00,0.05)
PFOS (branched isomers)	353	0.01 (−0.02,0.04)	200	−0.03 (−0.06,0.00)	363	0.00 (−0.03,0.04)
PFOA	354	0.03 (−0.01,0.07)	205	−0.01 (−0.05,0.03)	396	0.02 (−0.02,0.07)
PFHxS	354	0.02 (−0.00,0.04)	205	−0.00 (−0.03,0.02)	396	0.01 (−0.02,0.03)
LDL cholesterol (mmol/L)						
PFOS (total)	335	0.01 (−0.06,0.08)	205	0.06 (−0.03,0.15)	389	0.05 (−0.02,0.11)
PFOS (branched isomers)	334	0.01 (−0.07,0.10)	200	0.05 (−0.05,0.14)	356	0.06 (−0.02,0.14)
PFOA	335	0.17 (0.06,0.27)	205	0.05 (−0.07,0.17)	389	0.17 (0.06,0.27)
PFHxS	335	−0.01 (−0.07,0.04)	205	0.03 (−0.04,0.10)	389	0.06 (0.00,0.12)
Total:HDL cholesterol ratio						
PFOS (total)	354	−0.01 (−0.13,0.12)	205	0.06 (−0.06,0.17)	396	−0.00 (−0.07,0.07)
PFOS (branched isomers)	353	0.03 (−0.12,0.19)	200	0.06 (−0.09,0.21)	363	0.06 (−0.03,0.15)
PFOA	354	0.06 (−0.10,0.23)	205	−0.01 (−0.26,0.24)	396	0.14 (0.02,0.25)
PFHxS	354	−0.01 (−0.12,0.09)	205	0.02 (−0.09,0.14)	396	0.04 (−0.02,0.10)
Triglycerides (mmol/L)						
PFOS (total)	353	−0.06 (−0.14,0.02)	205	0.08 (−0.02,0.19)	396	−0.03 (−0.10,0.05)
PFOS (branched isomers)	352	−0.04 (−0.14,0.06)	200	0.04 (−0.08,0.15)	363	−0.01 (−0.11,0.09)
PFOA	353	0.03 (−0.10,0.15)	205	−0.01 (−0.16,0.15)	396	0.05 (−0.08,0.17)
PFHxS	353	−0.06 (−0.12,0.01)	205	0.04 (−0.06,0.14)	396	−0.01 (−0.07,0.05)
Serum creatinine (umol/L)						
PFOS (total)	354	0.18 (−0.97,1.32)	205	−0.13 (−1.81,1.55)	396	0.55 (−0.43,1.53)
PFOS (branched isomers)	353	0.05 (−1.11,1.21)	200	−0.80 (−3.18,1.59)	363	−0.05 (−1.11,1.01)
PFOA	354	−0.13 (−2.91,2.66)	205	0.42 (−3.20,4.05)	396	−0.15 (−1.62,1.31)
PFHxS	354	−0.74 (−1.52,0.05)	205	−0.85 (−2.63,0.92)	396	0.05 (−0.85,0.95)
Urate (uric acid) (mmol/L)						
PFOS (total)	354	0.00 (−0.01,0.01)	205	0.00 (−0.00,0.01)	396	0.00 (−0.00,0.01)
PFOS (branched isomers)	353	0.00 (−0.01,0.01)	200	0.00 (−0.01,0.01)	363	0.01 (0.00,0.01)

	Katherine, NT		Oakey, Qld		Williamtown, NSW	
	N Exposed	Difference[¶] (95% CI)	N Exposed	Difference[¶] (95% CI)	N Exposed	Difference[¶] (95% CI)
PFOA	354	0.02 (0.01,0.03)	205	0.01 (0.00,0.03)	396	0.02 (0.01,0.03)
PFHxS	354	−0.00 (−0.01,0.00)	205	−0.00 (−0.01,0.00)	396	0.00 (−0.00,0.01)
eGFR (mL/min/1.73 m2) CKD-EPI formula						
PFOS (total)	350	−0.06 (−1.03,0.91)	204	−0.24 (−1.78,1.30)	393	−0.39 (−1.27,0.49)
PFOS (branched isomers)	349	−0.06 (−1.14,1.02)	199	0.20 (−1.67,2.08)	361	0.02 (−0.95,0.99)
PFOA	350	−0.59 (−2.57,1.38)	204	−0.78 (−3.46,1.90)	393	−0.02 (−1.41,1.36)
PFHxS	350	0.65 (−0.10,1.40)	204	0.47 (−0.92,1.87)	393	−0.01 (−0.82,0.80)
ALT (U/L)						
PFOS (total)	322	−0.49 (−1.30,0.32)	203	0.26 (−0.68,1.21)	388	0.32 (−0.32,0.96)
PFOS (branched isomers)	321	−0.53 (−1.48,0.42)	198	0.37 (−0.80,1.53)	355	0.79 (−0.08,1.67)
PFOA	322	−0.38 (−1.44,0.67)	203	0.50 (−0.73,1.73)	388	0.42 (−0.66,1.51)
PFHxS	322	−0.49 (−1.13,0.16)	203	0.03 (−0.71,0.77)	388	0.17 (−0.50,0.85)
AST (U/L)						
PFOS (total)	351	−0.80 (−1.49,−0.10)	205	0.60 (−0.41,1.61)	395	0.14 (−0.30,0.58)
PFOS (branched isomers)	350	−0.75 (−1.62,0.11)	200	0.34 (−0.56,1.24)	362	0.31 (−0.29,0.91)
PFOA	351	−0.41 (−1.27,0.45)	205	1.47 (0.51,2.44)	395	0.82 (−0.00,1.64)
PFHxS	351	−0.70 (−1.26,−0.15)	205	0.28 (−0.46,1.02)	395	−0.05 (−0.52,0.43)
GGT (U/L)						
PFOS (total)	354	1.43 (−0.94,3.79)	205	1.48 (−0.64,3.61)	396	2.16 (−0.62,4.95)
PFOS (branched isomers)	353	1.06 (−1.74,3.85)	200	1.32 (−1.26,3.90)	363	0.82 (−1.34,2.98)
PFOA	354	0.86 (−1.66,3.37)	205	1.71 (−1.17,4.60)	396	2.01 (−0.54,4.57)
PFHxS	354	1.11 (−0.57,2.79)	205	−0.57 (−2.44,1.30)	396	1.25 (−0.82,3.33)
ALP (U/L)						
PFOS (total)	354	0.86 (−1.68,3.39)	205	−0.17 (−1.87,1.53)	395	−1.90 (−3.17,−0.62)
PFOS (branched isomers)	353	1.11 (−2.33,4.55)	200	1.12 (−0.85,3.08)	362	−0.09 (−1.81,1.63)
PFOA	354	2.47 (−1.50,6.45)[#]	205	0.37 (−2.14,2.89)	395	−0.45 (−2.96,2.06)
PFHxS	354	0.77 (−1.48,3.02)	205	−0.13 (−1.62,1.35)	395	−1.48 (−2.74,−0.23)
Serum albumin (g/L)						
PFOS (total)	354	0.05 (−0.20,0.30)	205	0.27 (−0.05,0.59)	396	0.19 (0.00,0.39)
PFOS (branched isomers)	353	0.09 (−0.19,0.37)	200	0.28 (−0.05,0.61)	363	0.27 (0.03,0.51)
PFOA	354	0.62 (0.20,1.03)	205	0.38 (−0.04,0.80)	396	0.55 (0.22,0.88)
PFHxS	354	0.00 (−0.19,0.20)	205	0.15 (−0.08,0.38)	396	0.16 (−0.01,0.34)
Total protein (g/L)						
PFOS (total)	354	0.20 (−0.17,0.57)	205	0.54 (0.07,1.00)	396	0.12 (−0.19,0.44)
PFOS (branched isomers)	353	0.27 (−0.20,0.75)	200	0.45 (−0.04,0.93)	363	0.34 (−0.06,0.75)
PFOA	354	0.68 (0.14,1.23)	205	0.44 (−0.16,1.04)	396	0.67 (0.20,1.15)

	Katherine, NT		Oakey, Qld		Williamtown, NSW	
	N Exposed	Difference¶ (95% CI)	N Exposed	Difference¶ (95% CI)	N Exposed	Difference¶ (95% CI)
PFHxS	354	0.06 (−0.27,0.40)	205	0.27 (−0.08,0.61)	396	0.18 (−0.11,0.47)
TSH (mIU/L)						
PFOS (total)	353	−0.01 (−0.06,0.04)	205	−0.00 (−0.07,0.06)	393	−0.00 (−0.06,0.05)
PFOS (branched isomers)	352	0.00 (−0.06,0.06)	200	0.01 (−0.06,0.09)	360	−0.01 (−0.08,0.06)
PFOA	353	0.09 (−0.01,0.19)	205	0.12 (−0.01,0.24)	393	0.01 (−0.08,0.11)
PFHxS	353	−0.01 (−0.05,0.04)	205	−0.02 (−0.07,0.04)	393	−0.02 (−0.07,0.03)
Free T3 (pmol/L)						
PFOS (total)	354	−0.01 (−0.05,0.04)	205	0.03 (−0.01,0.08)	394	0.02 (−0.01,0.06)
PFOS (branched isomers)	353	0.01 (−0.04,0.06)	200	0.04 (−0.01,0.10)	361	0.05 (0.00,0.09)
PFOA	354	0.00 (−0.09,0.10)	205	0.02 (−0.06,0.09)	394	0.03 (−0.03,0.10)
PFHxS	354	0.02 (−0.02,0.06)	205	0.00 (−0.04,0.05)	394	0.01 (−0.02,0.04)
Free T4 (pmol/L)						
PFOS (total)	353	0.05 (−0.04,0.14)	205	0.09 (−0.03,0.20)	394	0.01 (−0.09,0.11)
PFOS (branched isomers)	352	0.06 (−0.04,0.17)	200	0.12 (−0.03,0.26)	361	0.01 (−0.11,0.14)
PFOA	353	0.07 (−0.11,0.26)	205	0.16 (−0.02,0.33)	394	0.07 (−0.10,0.25)
PFHxS	353	0.03 (−0.05,0.10)	205	0.09 (−0.00,0.18)	394	0.09 (0.00,0.18)

N: sample size; NC: convergence not achieved.

¶ Adjusted for age, sex, level of education and gross household annual income. Age was modelled using a restricted cubic spline with 3 knots.

Estimated assuming an independence (rather than exchangeable) within-cluster correlation structure and cluster-robust standard errors.

Biochemical marker sensitivity analysis 10: exclusion of participants diagnosed with comorbidities in last 5 years

Table A6-21. Adjusted prevalence ratios of adverse lipid, liver, kidney and thyroid function biomarker concentrations per doubling in PFAS serum concentrations for residents and workers of PFAS Management Areas, 2016–2020. Sensitivity analysis: exclusion of participants diagnosed with comorbidities in last five years.

	Katherine, NT		Oakey, Qld		Williamtown, NSW	
	N (cases) Exposed	PR‡ (95% CI)	N (cases) Exposed	PR‡ (95% CI)	N (cases) Exposed	PR‡ (95% CI)
High total cholesterol (>5.5 mmol/L)						
PFOS (total)	200 (71)	1.00 (0.87,1.16)	117 (41)	1.02 (0.87,1.19)	217 (80)	1.12 (1.00,1.26)
PFOS (branched isomers)	200 (71)	0.97 (0.83,1.13)	114 (41)	0.99 (0.80,1.22)	200 (71)	1.22 (1.07,1.39)
PFOA	200 (71)	1.17 (0.89,1.53)	117 (41)	0.98 (0.75,1.28)	217 (80)	1.29 (1.06,1.56)
PFHxS	200 (71)	0.94 (0.84,1.05)	117 (41)	1.02 (0.90,1.17)	217 (80)	1.15 (1.04,1.28)
Low HDL cholesterol^						
PFOS (total)	200 (20)	0.75 (0.51,1.10)	117 (9)	1.01 (0.56,1.80)	217 (16)	0.68 (0.44,1.05)
PFOS (branched isomers)	200 (20)	0.81 (0.55,1.19)	114 (8)	1.17 (0.63,2.16)	200 (15)	0.84 (0.56,1.25)
PFOA	200 (20)	0.81 (0.48,1.37)	117 (9)	0.92 (0.47,1.81)	217 (16)	0.89 (0.53,1.51)
PFHxS	200 (20)	0.81 (0.66,1.00)	117 (9)	1.16 (0.81,1.68)	217 (16)	0.84 (0.70,1.01)
High LDL cholesterol (>4 mmol/L)						
PFOS (total)	190 (29)	0.84 (0.67,1.05)	117 (16)	0.90 (0.65,1.24)#	214 (31)	0.97 (0.78,1.20)
PFOS (branched isomers)	190 (29)	0.81 (0.61,1.06)	114 (16)	0.98 (0.72,1.32)#	197 (26)	1.16 (0.92,1.47)
PFOA	190 (29)	0.90 (0.58,1.38)	117 (16)	0.77 (0.52,1.15)#	214 (31)	1.42 (1.07,1.86)
PFHxS	190 (29)	0.86 (0.72,1.02)	117 (16)	0.95 (0.79,1.15)	214 (31)	1.13 (0.95,1.35)
High total:HDL cholesterol ratio (>4.5)						
PFOS (total)	200 (46)	0.84 (0.71,0.98)	117 (40)	1.06 (0.87,1.30)	217 (59)	0.97 (0.82,1.15)
PFOS (branched isomers)	200 (46)	0.93 (0.76,1.14)	114 (39)	1.18 (0.94,1.49)	200 (57)	1.03 (0.87,1.22)
PFOA	200 (46)	1.06 (0.75,1.50)	117 (40)	0.89 (0.70,1.13)	217 (59)	1.35 (1.02,1.80)
PFHxS	200 (46)	0.91 (0.79,1.05)	117 (40)	1.02 (0.87,1.19)	217 (59)	1.09 (0.97,1.23)

	Katherine, NT		Oakey, Qld		Williamtown, NSW	
	N (cases) Exposed	PR‡ (95% CI)	N (cases) Exposed	PR‡ (95% CI)	N (cases) Exposed	PR‡ (95% CI)
High triglycerides (>2 mmol/L)						
PFOS (total)	200 (60)	0.85 (0.73,0.99)	117 (49)	1.04 (0.87,1.25)	217 (71)	0.98 (0.84,1.14)
PFOS (branched isomers)	200 (60)	0.88 (0.75,1.04)	114 (47)	1.09 (0.89,1.35)	200 (69)	1.01 (0.86,1.19)
PFOA	200 (60)	1.01 (0.78,1.30)	117 (49)	1.04 (0.82,1.32)	217 (71)	1.14 (0.90,1.44)
PFHxS	200 (60)	0.89 (0.79,1.00)	117 (49)	1.07 (0.93,1.24)	217 (71)	1.01 (0.90,1.13)
High serum creatinine^						
PFOS (total)	200 (5)	0.71 (0.56,0.91)	117 (9)	1.20 (0.55,2.66)	217 (6)	1.20 (0.79,1.82)
PFOS (branched isomers)	200 (5)	0.89 (0.53,1.50)	114 (8)	0.96 (0.29,3.16)	200 (4)	1.05 (0.53,2.08)
PFOA	200 (5)	1.64 (0.91,2.95)	117 (9)	0.90 (0.30,2.76)	217 (6)	1.92 (1.29,2.87)
PFHxS	200 (5)	0.72 (0.59,0.87)	117 (9)	1.01 (0.51,2.00)	217 (6)	0.90 (0.53,1.53)
High urate (uric acid)^						
PFOS (total)	200 (13)	1.16 (0.87,1.55)	117 (5)	1.42 (0.73,2.76)	217 (16)	1.19 (0.90,1.58)
PFOS (branched isomers)	200 (13)	1.23 (0.92,1.66)	114 (4)	0.53 (0.13,2.12)	200 (14)	1.50 (1.06,2.12)
PFOA	200 (13)	2.83 (1.28,6.26)	117 (5)	0.58 (0.21,1.60)	217 (16)	1.70 (1.03,2.80)
PFHxS	200 (13)	1.04 (0.80,1.36)	117 (5)	0.95 (0.35,2.59)	217 (16)	1.10 (0.81,1.49)
Low eGFR (<60 mL/min/1.73 m2) CKD-EPI formula						
PFOS (total)	199 (4)	0.96 (0.62,1.48)	117 (7)	1.18 (0.46,3.00)	215 (6)	1.17 (0.75,1.84)
PFOS (branched isomers)	199 (4)	1.11 (0.69,1.78)	114 (7)	1.23 (0.35,4.30)	199 (4)	0.66 (0.38,1.15)
PFOA	199 (4)	4.14 (0.76,22.68)	117 (7)	1.22 (0.20,7.25)	215 (6)	1.20 (0.56,2.55)
PFHxS	199 (4)	0.94 (0.66,1.33)	117 (7)	0.93 (0.46,1.90)	215 (6)	0.89 (0.50,1.57)
High ALT^						
PFOS (total)	179 (9)	0.80 (0.49,1.28)	116 (9)	NC	214 (7)	1.61 (1.02,2.55)
PFOS (branched isomers)	179 (9)	0.69 (0.41,1.18)	113 (8)	NC	197 (7)	1.60 (0.95,2.69)

	Katherine, NT		Oakey, Qld		Williamtown, NSW	
	N (cases) Exposed	PR‡ (95% CI)	N (cases) Exposed	PR‡ (95% CI)	N (cases) Exposed	PR‡ (95% CI)
PFOA	179 (9)	0.72 (0.46,1.12)	116 (9)	NC	214 (7)	1.05 (0.55,2.03)
PFHxS	179 (9)	0.79 (0.58,1.08)#	116 (9)	NC	214 (7)	1.35 (0.90,2.03)
High AST^						
PFOS (total)	199 (10)	0.88 (0.57,1.36)	117 (6)	1.21 (0.53,2.72)	216 (2)	0.46 (0.15,1.42)
PFOS (branched isomers)	199 (10)	0.84 (0.49,1.44)	114 (4)	0.72 (0.25,2.10)	199 (2)	0.40 (0.10,1.68)
PFOA	199 (10)	0.75 (0.45,1.27)	117 (6)	1.10 (0.65,1.85)	216 (2)	0.53 (0.05,5.81)
PFHxS	199 (10)	0.89 (0.61,1.32)	117 (6)	1.17 (0.59,2.33)	216 (2)	0.57 (0.32,1.03)
High GGT^						
PFOS (total)	200 (23)	0.90 (0.71,1.12)	117 (14)	1.25 (0.86,1.80)	217 (28)	1.06 (0.82,1.38)
PFOS (branched isomers)	200 (23)	0.85 (0.65,1.09)	114 (13)	1.23 (0.72,2.12)	200 (27)	1.07 (0.81,1.41)
PFOA	200 (23)	1.06 (0.74,1.52)	117 (14)	1.34 (0.58,3.10)	217 (28)	1.48 (0.96,2.27)
PFHxS	200 (23)	0.96 (0.82,1.12)	117 (14)	0.97 (0.67,1.40)	217 (28)	1.00 (0.83,1.20)
High ALP^						
PFOS (total)	200 (8)	NC	117 (8)	0.94 (0.56,1.60)	216 (12)	0.94 (0.73,1.19)
PFOS (branched isomers)	200 (8)	NC	114 (8)	1.13 (0.62,2.05)	199 (11)	1.18 (0.89,1.56)
PFOA	200 (8)	NC	117 (8)	0.84 (0.56,1.27)	216 (12)	1.36 (0.60,3.05)
PFHxS	200 (8)	NC	117 (8)	1.02 (0.70,1.49)	216 (12)	1.04 (0.79,1.37)
Abnormal TSH^						
PFOS (total)	200 (7)	1.19 (0.87,1.64)	117 (3)	0.50 (0.22,1.15)	216 (8)	1.26 (0.87,1.84)
PFOS (branched isomers)	200 (7)	1.20 (0.83,1.74)	114 (3)	0.63 (0.30,1.35)	199 (6)	1.22 (0.58,2.54)
PFOA	200 (7)	1.90 (0.76,4.75)	117 (3)	3.17 (1.48,6.77)	216 (8)	0.74 (0.35,1.58)
PFHxS	200 (7)	0.94 (0.74,1.20)	117 (3)	0.58 (0.41,0.82)	216 (8)	1.24 (0.86,1.77)

N: sample size; PR: prevalence ratio; NC: convergence not achieved.

‡ Adjusted for age, sex, level of education and gross household annual income. Age was modelled using a restricted cubic spline with 3 knots.

^ Reference intervals vary by sex and age.

Estimated assuming an independence (rather than exchangeable) within-cluster correlation structure and cluster-robust standard errors.

Comorbidities included ten cancers, cardiovascular outcomes (high blood pressure, hypercholesterolaemia, stroke and heart attack), autoimmune outcomes (lupus, ulcerative colitis, Crohn's disease, multiple sclerosis, rheumatoid arthritis and asthma), diabetes, liver disease (non-infectious hepatitis, fatty liver disease and cirrhosis of the liver), hypo- and hyperthyroidism, chronic kidney disease, and gout, as self-reported in the Cross-sectional Survey.

Table A6-22. Differences in mean lipid, liver, kidney and thyroid function biomarker concentrations per doubling in PFAS serum concentrations for residents and workers of PFAS Management Areas, 2016–2020. Sensitivity analysis: exclusion of participants diagnosed with comorbidities in last five years.

	Katherine, NT		Oakey, Qld		Williamtown, NSW	
	N Exposed	Difference[¶] (95% CI)	N Exposed	Difference[¶] (95% CI)	N Exposed	Difference[¶] (95% CI)
Total cholesterol (mmol/L)						
PFOS (total)	200	−0.08 (−0.18,0.01)	117	0.04 (−0.10,0.19)	217	0.09 (−0.02,0.19)
PFOS (branched isomers)	200	−0.11 (−0.21,−0.00)	114	−0.04 (−0.28,0.20)	200	0.10 (−0.02,0.23)
PFOA	200	0.07 (−0.08,0.22)	117	−0.05 (−0.38,0.28)	217	0.20 (0.05,0.36)
PFHxS	200	−0.10 (−0.18,−0.02)	117	−0.02 (−0.19,0.16)	217	0.10 (0.01,0.20)
HDL cholesterol (mmol/L)						
PFOS (total)	200	0.02 (−0.01,0.06)	117	−0.01 (−0.06,0.03)	217	0.03 (−0.01,0.06)
PFOS (branched isomers)	200	0.01 (−0.03,0.04)	114	−0.04 (−0.08,0.01)	200	0.01 (−0.03,0.05)
PFOA	200	0.03 (−0.03,0.09)	117	0.01 (−0.05,0.07)	217	−0.01 (−0.06,0.04)
PFHxS	200	0.01 (−0.01,0.04)	117	−0.01 (−0.04,0.02)	217	0.01 (−0.02,0.03)
LDL cholesterol (mmol/L)						
PFOS (total)	190	−0.06 (−0.15,0.04)	117	0.05 (−0.06,0.16)	214	0.03 (−0.06,0.12)
PFOS (branched isomers)	190	−0.09 (−0.19,0.02)	114	0.02 (−0.11,0.15)	197	0.05 (−0.06,0.16)
PFOA	190	0.04 (−0.11,0.19)	117	0.05 (−0.09,0.20)	214	0.14 (0.01,0.27)
PFHxS	190	−0.09 (−0.17,−0.02)	117	0.00 (−0.08,0.08)	214	0.09 (0.01,0.16)
Total:HDL cholesterol ratio						
PFOS (total)	200	−0.14 (−0.24,−0.03)	117	0.08 (−0.10,0.26)	217	0.00 (−0.11,0.12)
PFOS (branched isomers)	200	−0.11 (−0.22,0.01)	114	0.07 (−0.19,0.34)	200	0.06 (−0.07,0.20)
PFOA	200	−0.03 (−0.24,0.18)	117	−0.10 (−0.45,0.25)	217	0.21 (0.04,0.37)
PFHxS	200	−0.11 (−0.19,−0.02)	117	0.03 (−0.16,0.22)	217	0.07 (−0.02,0.17)
Triglycerides (mmol/L)						
PFOS (total)	200	−0.14 (−0.24,−0.04)	117	0.09 (−0.08,0.26)	217	0.04 (−0.07,0.14)
PFOS (branched isomers)	200	−0.11 (−0.22,−0.01)	114	0.03 (−0.13,0.19)	200	0.05 (−0.08,0.18)
PFOA	200	−0.02 (−0.21,0.16)	117	−0.03 (−0.23,0.17)	217	0.15 (−0.03,0.32)
PFHxS	200	−0.11 (−0.18,−0.03)	117	0.09 (−0.07,0.24)	217	0.02 (−0.08,0.12)
Serum creatinine (umol/L)						
PFOS (total)	200	−0.22 (−1.51,1.07)	117	0.57 (−2.09,3.22)	217	0.29 (−0.98,1.55)
PFOS (branched isomers)	200	0.38 (−1.18,1.93)	114	−1.02 (−5.31,3.27)	200	−0.07 (−1.62,1.49)
PFOA	200	0.20 (−1.84,2.24)	117	−0.45 (−5.90,5.00)	217	−0.90 (−2.88,1.08)
PFHxS	200	−1.01 (−1.95,−0.07)	117	−0.58 (−3.44,2.28)	217	−0.20 (−1.45,1.05)
Urate (uric acid) (mmol/L)						
PFOS (total)	200	−0.00 (−0.01,0.01)	117	0.00 (−0.01,0.01)	217	0.00 (−0.00,0.01)
PFOS (branched isomers)	200	0.00 (−0.01,0.01)	114	−0.01 (−0.02,0.01)[#]	200	0.01 (−0.00,0.02)

	Katherine, NT		Oakey, Qld		Williamtown, NSW	
	N Exposed	Difference[¶] (95% CI)	N Exposed	Difference[¶] (95% CI)	N Exposed	Difference[¶] (95% CI)
PFOA	200	0.02 (0.00,0.03)	117	0.01 (−0.01,0.02)	217	0.02 (0.00,0.03)
PFHxS	200	−0.00 (−0.01,0.00)	117	−0.00 (−0.01,0.01)	217	0.00 (−0.00,0.01)
eGFR (mL/min/1.73 m2) CKD-EPI formula						
PFOS (total)	199	0.04 (−1.22,1.30)	117	−0.84 (−3.15,1.48)	215	−0.16 (−1.35,1.04)
PFOS (branched isomers)	199	−0.51 (−2.03,1.00)	114	0.31 (−2.96,3.58)	199	0.04 (−1.40,1.49)
PFOA	199	−0.69 (−2.78,1.41)	117	−0.04 (−3.93,3.84)	215	0.86 (−1.15,2.88)
PFHxS	199	0.84 (−0.12,1.80)	117	0.06 (−2.12,2.24)	215	0.24 (−0.87,1.36)
ALT (U/L)						
PFOS (total)	179	−1.09 (−2.19,0.00)	116	0.25 (−1.35,1.86)	214	0.41 (−0.47,1.30)
PFOS (branched isomers)	179	−1.20 (−2.36,−0.05)	113	0.63 (−1.35,2.60)	197	0.95 (−0.08,1.98)
PFOA	179	−1.03 (−2.53,0.47)	116	−0.14 (−1.77,1.49)	214	0.50 (−0.97,1.97)
PFHxS	179	−1.06 (−2.01,−0.11)	116	0.26 (−0.86,1.38)	214	0.44 (−0.20,1.08)
AST (U/L)						
PFOS (total)	199	−0.81 (−2.00,0.38)	117	0.47 (−1.08,2.02)	216	0.04 (−0.57,0.65)
PFOS (branched isomers)	199	−0.65 (−2.05,0.75)	114	−0.06 (−1.40,1.27)	199	0.26 (−0.43,0.95)
PFOA	199	−0.71 (−2.17,0.76)	117	1.08 (−0.03,2.19)	216	0.57 (−0.49,1.64)
PFHxS	199	−0.78 (−1.72,0.16)	117	0.43 (−0.71,1.58)	216	0.12 (−0.39,0.62)
GGT (U/L)						
PFOS (total)	200	1.71 (−2.46,5.88)	117	1.54 (−1.46,4.54)	217	0.56 (−1.67,2.78)
PFOS (branched isomers)	200	1.07 (−3.65,5.79)	114	1.53 (−2.48,5.55)	200	0.37 (−2.12,2.86)
PFOA	200	1.35 (−3.06,5.75)	117	−0.16 (−2.86,2.54)	217	2.41 (−0.20,5.02)
PFHxS	200	1.71 (−1.15,4.56)	117	0.38 (−1.84,2.60)	217	−0.29 (−1.98,1.40)
ALP (U/L)						
PFOS (total)	200	0.64 (−2.05,3.33)	117	−1.60 (−4.09,0.88)	216	−1.77 (−3.63,0.10)
PFOS (branched isomers)	200	0.12 (−2.71,2.95)	114	0.20 (−2.72,3.12)	199	0.18 (−2.06,2.42)
PFOA	200	2.23 (−1.39,5.84)	117	−1.29 (−4.58,2.01)	216	−0.38 (−4.07,3.32)
PFHxS	200	0.48 (−1.77,2.73)	117	−0.56 (−2.59,1.46)	216	−1.55 (−3.24,0.14)
Serum albumin (g/L)						
PFOS (total)	200	−0.02 (−0.34,0.31)	117	0.23 (−0.17,0.62)	217	0.06 (−0.20,0.32)
PFOS (branched isomers)	200	−0.01 (−0.35,0.32)	114	0.17 (−0.30,0.64)	200	0.15 (−0.18,0.47)
PFOA	200	0.27 (−0.25,0.79)	117	0.43 (−0.16,1.02)	217	0.06 (−0.34,0.47)
PFHxS	200	−0.09 (−0.36,0.18)	117	0.08 (−0.21,0.38)	217	0.01 (−0.23,0.25)
Total protein (g/L)						
PFOS (total)	200	0.01 (−0.46,0.48)	117	0.47 (−0.12,1.05)	217	−0.14 (−0.60,0.32)
PFOS (branched isomers)	200	0.04 (−0.48,0.57)	114	0.17 (−0.47,0.81)	200	0.06 (−0.50,0.61)
PFOA	200	0.55 (−0.18,1.28)	117	0.33 (−0.32,0.97)	217	0.19 (−0.44,0.83)

	Katherine, NT		Oakey, Qld		Williamtown, NSW	
	N Exposed	Difference¶ (95% CI)	N Exposed	Difference¶ (95% CI)	N Exposed	Difference¶ (95% CI)
PFHxS	200	−0.21 (−0.64,0.22)	117	0.35 (−0.09,0.78)	217	−0.09 (−0.50,0.33)
TSH (mIU/L)						
PFOS (total)	200	−0.03 (−0.10,0.04)	117	−0.04 (−0.15,0.06)	216	0.01 (−0.07,0.08)
PFOS (branched isomers)	200	−0.02 (−0.10,0.06)	114	0.01 (−0.11,0.12)	199	−0.01 (−0.10,0.08)
PFOA	200	0.16 (0.03,0.28)	117	0.14 (−0.04,0.32)	216	0.06 (−0.06,0.18)
PFHxS	200	−0.01 (−0.06,0.05)	117	−0.04 (−0.12,0.04)	216	−0.02 (−0.08,0.04)
Free T3 (pmol/L)						
PFOS (total)	200	−0.00 (−0.04,0.04)	117	0.01 (−0.06,0.09)	216	−0.00 (−0.05,0.05)
PFOS (branched isomers)	200	0.02 (−0.03,0.08)	114	0.02 (−0.07,0.11)	199	0.05 (−0.02,0.11)
PFOA	200	0.02 (−0.05,0.10)	117	−0.02 (−0.10,0.07)	216	0.02 (−0.07,0.11)
PFHxS	200	0.01 (−0.03,0.05)	117	0.01 (−0.05,0.06)	216	0.01 (−0.04,0.05)
Free T4 (pmol/L)						
PFOS (total)	199	0.04 (−0.09,0.17)#	117	0.12 (−0.03,0.28)	216	−0.00 (−0.15,0.14)
PFOS (branched isomers)	199	0.08 (−0.06,0.22)#	114	0.15 (−0.02,0.32)	199	0.09 (−0.07,0.25)
PFOA	199	0.07 (−0.16,0.30)#	117	0.14 (−0.06,0.34)	216	0.04 (−0.17,0.26)
PFHxS	199	0.01 (−0.09,0.11)#	117	0.09 (−0.04,0.21)	216	0.06 (−0.05,0.18)

N: sample size; NC: convergence not achieved.

¶ Adjusted for age, sex, level of education and gross household annual income. Age was modelled using a restricted cubic spline with 3 knots.

Estimated assuming an independence (rather than exchangeable) within-cluster correlation structure and cluster-robust standard errors.

Comorbidities included ten cancers, cardiovascular outcomes (high blood pressure, hypercholesterolaemia, stroke and heart attack), autoimmune outcomes (lupus, ulcerative colitis, Crohn's disease, multiple sclerosis, rheumatoid arthritis and asthma), diabetes, liver disease (non-infectious hepatitis, fatty liver disease and cirrhosis of the liver), hypo- and hyperthyroidism, chronic kidney disease, and gout, as self-reported in the Cross-sectional Survey.

Biochemical marker sensitivity analysis 11: exclusion of participants with declining kidney function (eGFR <60)

Table A6-23. Adjusted prevalence ratios of adverse lipid, liver, kidney and thyroid function biomarker concentrations per doubling in PFAS serum concentrations for residents and workers of PFAS Management Areas, 2016–2020. Sensitivity analysis: exclusion of participants with declining kidney function.

	Katherine, NT		Oakey, Qld		Williamtown, NSW	
	N (cases) Exposed	PR‡ (95% CI)	N (cases) Exposed	PR‡ (95% CI)	N (cases) Exposed	PR‡ (95% CI)
High total cholesterol (>5.5 mmol/L)						
PFOS (total)	242 (88)	1.04 (0.93,1.15)	144 (48)	1.10 (0.96,1.26)	266 (98)	1.12 (1.02,1.25)
PFOS (branched isomers)	242 (88)	1.02 (0.90,1.15)	141 (48)	1.12 (0.92,1.37)	247 (88)	1.17 (1.04,1.32)
PFOA	242 (88)	1.19 (0.98,1.44)	144 (48)	1.17 (0.90,1.52)	266 (98)	1.30 (1.10,1.55)
PFHxS	242 (88)	0.99 (0.91,1.08)	144 (48)	1.11 (0.99,1.25)	266 (98)	1.15 (1.05,1.27)
Low HDL cholesterol^						
PFOS (total)	242 (31)	0.84 (0.64,1.10)	144 (14)	0.84 (0.54,1.32)	266 (25)	0.89 (0.68,1.17)#
PFOS (branched isomers)	242 (31)	0.94 (0.71,1.26)	141 (13)	0.90 (0.55,1.47)	247 (24)	1.05 (0.78,1.42)#
PFOA	242 (31)	0.86 (0.57,1.30)	144 (14)	0.98 (0.58,1.64)	266 (25)	0.97 (0.65,1.44)#
PFHxS	242 (31)	0.85 (0.72,1.01)	144 (14)	1.06 (0.79,1.44)	266 (25)	0.97 (0.82,1.15)#
High LDL cholesterol (>4 mmol/L)						
PFOS (total)	227 (35)	1.00 (0.79,1.26)	144 (19)	1.01 (0.80,1.28)	261 (40)	1.03 (0.87,1.22)
PFOS (branched isomers)	227 (35)	0.95 (0.72,1.24)	141 (19)	1.06 (0.80,1.40)	242 (34)	1.05 (0.86,1.28)
PFOA	227 (35)	1.11 (0.73,1.69)	144 (19)	0.92 (0.66,1.27)	261 (40)	1.35 (1.03,1.78)
PFHxS	227 (35)	0.95 (0.79,1.15)	144 (19)	1.00 (0.84,1.20)	261 (40)	1.08 (0.92,1.27)
High total:HDL cholesterol ratio (>4.5)						
PFOS (total)	242 (65)	0.93 (0.81,1.06)	144 (45)	1.05 (0.87,1.26)	266 (75)	1.02 (0.90,1.15)
PFOS (branched isomers)	242 (65)	1.02 (0.87,1.19)	141 (44)	1.20 (0.98,1.48)	247 (72)	1.07 (0.93,1.23)
PFOA	242 (65)	1.10 (0.85,1.44)	144 (45)	0.96 (0.75,1.22)	266 (75)	1.26 (1.00,1.59)
PFHxS	242 (65)	0.95 (0.85,1.07)	144 (45)	1.03 (0.89,1.19)	266 (75)	1.07 (0.96,1.19)
High triglycerides (>2 mmol/L)						
PFOS (total)	242 (84)	0.90 (0.79,1.04)	144 (60)	1.01 (0.86,1.18)	266 (91)	1.00 (0.88,1.14)
PFOS (branched isomers)	242 (84)	0.94 (0.81,1.09)	141 (58)	1.09 (0.90,1.32)	247 (89)	1.04 (0.90,1.20)
PFOA	242 (84)	1.07 (0.86,1.33)	144 (60)	1.08 (0.87,1.33)	266 (91)	1.14 (0.93,1.40)
PFHxS	242 (84)	0.92 (0.83,1.02)	144 (60)	1.07 (0.95,1.22)	266 (91)	1.02 (0.92,1.14)
High urate (uric acid)^						
PFOS (total)	242 (16)	1.16 (0.97,1.40)	144 (7)	NC	266 (19)	1.23 (0.98,1.54)#
PFOS (branched isomers)	242 (16)	1.17 (0.95,1.45)	141 (6)	NC	247 (17)	1.44 (1.08,1.92)#
PFOA	242 (16)	2.20 (1.39,3.48)	144 (7)	1.81 (0.81,4.05)	266 (19)	1.80 (1.15,2.81)#
PFHxS	242 (16)	0.99 (0.81,1.21)	144 (7)	NC	266 (19)	1.09 (0.85,1.41)#

	Katherine, NT		Oakey, Qld		Williamtown, NSW	
	N (cases) Exposed	PR‡ (95% CI)	N (cases) Exposed	PR‡ (95% CI)	N (cases) Exposed	PR‡ (95% CI)
High ALT^						
PFOS (total)	220 (11)	0.99 (0.64,1.53)	143 (9)	NC	264 (11)	1.54 (1.07,2.20)
PFOS (branched isomers)	220 (11)	0.95 (0.57,1.61)	140 (8)	NC	245 (11)	1.59 (1.00,2.54)
PFOA	220 (11)	0.89 (0.59,1.33)	143 (9)	NC	264 (11)	1.11 (0.66,1.88)
PFHxS	220 (11)	0.94 (0.69,1.29)	143 (9)	NC	264 (11)	1.25 (0.80,1.95)
High AST^						
PFOS (total)	241 (10)	0.92 (0.62,1.35)	144 (8)	1.42 (0.92,2.20)	266 (4)	0.61 (0.40,0.95)
PFOS (branched isomers)	241 (10)	0.86 (0.51,1.44)	141 (6)	1.21 (0.57,2.58)	247 (4)	0.56 (0.26,1.18)
PFOA	241 (10)	0.80 (0.51,1.27)	144 (8)	1.64 (0.92,2.93)	266 (4)	0.87 (0.30,2.49)
PFHxS	241 (10)	0.94 (0.66,1.33)	144 (8)	1.21 (0.82,1.76)	266 (4)	0.59 (0.39,0.91)
High GGT^						
PFOS (total)	242 (30)	0.99 (0.83,1.17)	144 (23)	1.01 (0.79,1.30)	266 (43)	1.22 (0.98,1.52)
PFOS (branched isomers)	242 (30)	0.94 (0.74,1.19)	141 (22)	1.16 (0.85,1.57)	247 (41)	1.34 (0.98,1.84)
PFOA	242 (30)	1.07 (0.79,1.46)	144 (23)	1.52 (1.05,2.20)	266 (43)	1.39 (0.96,2.02)
PFHxS	242 (30)	0.97 (0.84,1.12)	144 (23)	0.98 (0.81,1.19)	266 (43)	1.16 (0.98,1.38)
High ALP^						
PFOS (total)	242 (11)	NC	144 (8)	1.03 (0.63,1.67)	266 (16)	1.24 (0.97,1.58)
PFOS (branched isomers)	242 (11)	NC	141 (8)	1.32 (0.69,2.54)	247 (14)	1.41 (1.06,1.88)
PFOA	242 (11)	NC	144 (8)	0.83 (0.60,1.14)	266 (16)	1.60 (0.85,2.99)
PFHxS	242 (11)	NC	144 (8)	1.15 (0.79,1.68)	266 (16)	0.97 (0.72,1.31)
Abnormal TSH^						
PFOS (total)	242 (8)	NC	144 (2)	0.84 (0.49,1.44)	265 (10)	1.22 (0.89,1.67)
PFOS (branched isomers)	242 (8)	NC	141 (2)	0.78 (0.37,1.63)	246 (7)	NC
PFOA	242 (8)	NC	144 (2)	11.64 (4.28,31.63)	265 (10)	0.85 (0.47,1.54)
PFHxS	242 (8)	NC	144 (2)	0.59 (0.37,0.92)	265 (10)	1.25 (0.91,1.72)

N: sample size; PR: prevalence ratio; NC: convergence not achieved.

‡ Adjusted for age, sex, level of education and gross household annual income. Age was modelled using a restricted cubic spline with 3 knots.

^ Reference intervals vary by sex and age.

Estimated assuming an independence (rather than exchangeable) within-cluster correlation structure and cluster-robust standard errors.

Table A6-24. Differences in mean lipid, liver, kidney and thyroid function biomarker concentrations per doubling in PFAS serum concentrations for residents and workers of PFAS Management Areas, 2016–2020. Sensitivity analysis: exclusion of participants with declining kidney function.

	Katherine, NT		Oakey, Qld		Williamtown, NSW	
	N Exposed	Difference[¶] (95% CI)	N Exposed	Difference[¶] (95% CI)	N Exposed	Difference[¶] (95% CI)
Total cholesterol (mmol/L)						
PFOS (total)	242	−0.01 (−0.11,0.08)	144	0.11 (−0.01,0.23)	266	0.09 (0.00,0.18)
PFOS (branched isomers)	242	−0.03 (−0.14,0.07)	141	0.10 (−0.04,0.24)	247	0.10 (0.00,0.20)
PFOA	242	0.14 (0.01,0.28)	144	0.14 (0.00,0.29)	266	0.19 (0.06,0.33)
PFHxS	242	−0.03 (−0.11,0.05)	144	0.09 (−0.02,0.19)	266	0.11 (0.03,0.19)
HDL cholesterol (mmol/L)						
PFOS (total)	242	0.02 (−0.01,0.05)	144	0.00 (−0.04,0.04)	266	0.03 (−0.00,0.07)
PFOS (branched isomers)	242	−0.00 (−0.04,0.03)	141	−0.02 (−0.06,0.02)	247	−0.00 (−0.04,0.03)
PFOA	242	0.03 (−0.02,0.07)	144	0.01 (−0.05,0.06)	266	0.00 (−0.05,0.06)
PFHxS	242	0.02 (−0.01,0.04)	144	−0.00 (−0.03,0.03)	266	0.01 (−0.02,0.04)
LDL cholesterol (mmol/L)						
PFOS (total)	227	0.01 (−0.08,0.10)	144	0.08 (−0.02,0.17)	261	0.05 (−0.02,0.13)
PFOS (branched isomers)	227	−0.01 (−0.11,0.09)	141	0.06 (−0.07,0.19)	242	0.04 (−0.05,0.13)
PFOA	227	0.13 (−0.01,0.26)	144	0.10 (−0.04,0.24)	261	0.14 (0.02,0.26)
PFHxS	227	−0.03 (−0.10,0.04)	144	0.03 (−0.05,0.11)	261	0.07 (0.00,0.14)
Total:HDL cholesterol ratio						
PFOS (total)	242	−0.06 (−0.16,0.04)	144	0.07 (−0.07,0.22)	266	−0.01 (−0.10,0.09)
PFOS (branched isomers)	242	−0.01 (−0.13,0.11)	141	0.14 (−0.00,0.28)	247	0.09 (−0.02,0.21)
PFOA	242	0.03 (−0.14,0.21)	144	0.09 (−0.08,0.27)	266	0.20 (0.05,0.35)
PFHxS	242	−0.06 (−0.14,0.02)	144	0.09 (−0.02,0.20)	266	0.06 (−0.02,0.15)
Triglycerides (mmol/L)						
PFOS (total)	242	−0.09 (−0.19,0.01)	144	0.05 (−0.10,0.21)	266	−0.00 (−0.11,0.10)
PFOS (branched isomers)	242	−0.07 (−0.18,0.05)	141	0.04 (−0.10,0.18)	247	0.06 (−0.05,0.17)
PFOA	242	0.01 (−0.14,0.16)	144	0.03 (−0.13,0.18)	266	0.11 (−0.03,0.24)
PFHxS	242	−0.07 (−0.14,0.01)	144	0.09 (−0.05,0.22)	266	0.04 (−0.03,0.12)
Urate (uric acid) (mmol/L)						
PFOS (total)	242	−0.00 (−0.01,0.01)	144	0.00 (−0.01,0.01)	266	0.00 (−0.00,0.01)
PFOS (branched isomers)	242	0.00 (−0.01,0.01)	141	−0.00 (−0.01,0.01)	247	0.01 (0.00,0.02)
PFOA	242	0.02 (0.01,0.03)	144	0.01 (−0.00,0.02)	266	0.02 (0.01,0.03)
PFHxS	242	−0.00 (−0.01,0.00)	144	0.00 (−0.01,0.01)	266	0.01 (−0.00,0.01)
ALT (U/L)						
PFOS (total)	220	−0.71 (−1.71,0.28)	143	0.09 (−1.04,1.23)	264	0.43 (−0.43,1.29)
PFOS (branched isomers)	220	−0.75 (−1.93,0.43)	140	0.14 (−1.33,1.61)	245	0.99 (−0.07,2.06)

	Katherine, NT		Oakey, Qld		Williamtown, NSW	
	N Exposed	Difference[¶] (95% CI)	N Exposed	Difference[¶] (95% CI)	N Exposed	Difference[¶] (95% CI)
PFOA	220	−0.42 (−1.62,0.78)	143	0.69 (−0.78,2.16)	264	0.57 (−0.62,1.75)
PFHxS	220	−0.71 (−1.50,0.08)	143	−0.09 (−0.97,0.79)	264	0.37 (−0.37,1.11)
AST (U/L)						
PFOS (total)	241	−0.68 (−1.67,0.31)	144	0.54 (−0.85,1.92)	266	0.16 (−0.38,0.70)
PFOS (branched isomers)	241	−0.63 (−1.80,0.54)	141	0.01 (−1.30,1.31)	247	0.30 (−0.37,0.97)
PFOA	241	−0.28 (−1.37,0.81)	144	1.57 (0.40,2.74)	266	0.79 (−0.09,1.67)
PFHxS	241	−0.67 (−1.41,0.07)	144	0.41 (−0.68,1.50)	266	−0.10 (−0.63,0.43)
GGT (U/L)						
PFOS (total)	242	1.63 (−2.05,5.30)	144	−0.38 (−2.52,1.76)	266	1.13 (−1.31,3.57)
PFOS (branched isomers)	242	1.11 (−2.99,5.22)	141	−0.06 (−2.51,2.39)	247	1.15 (−1.46,3.77)
PFOA	242	1.37 (−2.29,5.03)	144	1.39 (−1.06,3.85)	266	1.51 (−1.26,4.27)
PFHxS	242	1.48 (−1.02,3.98)	144	−0.02 (−1.70,1.66)	266	0.52 (−1.31,2.36)
ALP (U/L)						
PFOS (total)	242	0.34 (−1.84,2.53)	144	−1.12 (−3.26,1.02)	266	−1.17 (−2.92,0.58)
PFOS (branched isomers)	242	0.13 (−2.28,2.53)	141	0.82 (−2.02,3.66)	247	0.98 (−1.14,3.09)
PFOA	242	2.06 (−0.68,4.80)	144	−1.36 (−4.16,1.45)	266	1.72 (−1.19,4.63)
PFHxS	242	0.08 (−1.74,1.91)	144	0.11 (−1.85,2.07)	266	−0.98 (−2.49,0.53)
Serum albumin (g/L)						
PFOS (total)	242	−0.01 (−0.28,0.25)	144	0.39 (0.06,0.72)	266	0.08 (−0.14,0.31)
PFOS (branched isomers)	242	−0.03 (−0.32,0.26)	141	0.35 (−0.07,0.77)	247	0.11 (−0.17,0.39)
PFOA	242	0.12 (−0.28,0.51)	144	0.43 (−0.06,0.92)	266	0.26 (−0.12,0.63)
PFHxS	242	−0.11 (−0.33,0.11)	144	0.14 (−0.12,0.40)	266	0.09 (−0.13,0.30)
Total protein (g/L)						
PFOS (total)	242	−0.04 (−0.44,0.35)	144	0.48 (−0.08,1.05)	266	−0.13 (−0.49,0.24)
PFOS (branched isomers)	242	−0.06 (−0.51,0.40)	141	0.25 (−0.41,0.92)	247	0.10 (−0.36,0.56)
PFOA	242	0.29 (−0.27,0.84)	144	0.40 (−0.33,1.14)	266	0.34 (−0.17,0.86)
PFHxS	242	−0.21 (−0.55,0.14)	144	0.32 (−0.11,0.75)	266	0.11 (−0.23,0.46)
TSH (mIU/L)						
PFOS (total)	242	−0.02 (−0.08,0.04)	144	−0.01 (−0.09,0.07)	265	−0.01 (−0.06,0.05)
PFOS (branched isomers)	242	−0.01 (−0.08,0.06)	141	0.01 (−0.09,0.10)	246	−0.01 (−0.08,0.07)
PFOA	242	0.12 (0.01,0.22)	144	0.11 (−0.05,0.26)	265	0.04 (−0.06,0.14)
PFHxS	242	−0.00 (−0.05,0.05)	144	−0.02 (−0.09,0.05)	265	−0.03 (−0.08,0.03)
Free T3 (pmol/L)						
PFOS (total)	242	−0.01 (−0.05,0.03)	144	−0.00 (−0.06,0.06)	265	−0.01 (−0.05,0.03)
PFOS (branched isomers)	242	0.01 (−0.04,0.06)	141	−0.00 (−0.08,0.07)	246	0.03 (−0.02,0.09)
PFOA	242	−0.00 (−0.06,0.06)	144	−0.02 (−0.10,0.06)	265	−0.00 (−0.07,0.07)

	Katherine, NT		Oakey, Qld		Williamtown, NSW	
	N Exposed	Difference¶ (95% CI)	N Exposed	Difference¶ (95% CI)	N Exposed	Difference¶ (95% CI)
PFHxS	242	−0.00 (−0.03,0.03)	144	−0.00 (−0.05,0.04)	265	−0.01 (−0.05,0.03)
Free T4 (pmol/L)						
PFOS (total)	241	0.01 (−0.11,0.12)#	144	0.09 (−0.05,0.23)	265	−0.01 (−0.14,0.13)
PFOS (branched isomers)	241	0.04 (−0.08,0.17)#	141	0.14 (−0.02,0.30)	246	0.04 (−0.11,0.19)
PFOA	241	0.02 (−0.17,0.22)#	144	0.09 (−0.08,0.26)	265	−0.02 (−0.23,0.18)
PFHxS	241	−0.03 (−0.11,0.06)#	144	0.07 (−0.05,0.19)	265	0.08 (−0.04,0.19)

N: sample size; NC: convergence not achieved.

¶ Adjusted for age, sex, level of education and gross household annual income. Age was modelled using a restricted cubic spline with 3 knots.

Estimated assuming an independence (rather than exchangeable) within-cluster correlation structure and cluster-robust standard errors.

Biochemical marker analysis: comparison communities

Table A6-25. Crude prevalence ratios of adverse lipid concentrations and liver, kidney and thyroid function biomarker concentrations for residents of comparison communities, 2020.

	Alice Springs, NT		Dalby, Qld		Kiama and Shellharbour, NSW	
	N	Prevalence % (cases/N)	N	Prevalence % (cases/N)	N	Prevalence % (cases/N)
High total cholesterol (>5.5 mmol/L)	168	34.5% (58/168)	148	33.8% (50/148)	371	32.6% (121/371)
Low HDL cholesterol^	168	9.5% (16/168)	148	15.5% (23/148)	371	6.5% (24/371)
High LDL cholesterol (>4 mmol/L)	161	16.8% (27/161)	146	15.8% (23/146)	364	16.5% (60/364)
High total:HDL cholesterol ratio (>4.5 mmol/L)	168	22.6% (38/168)	148	24.3% (36/148)	371	13.7% (51/371)
High triglycerides (>2 mmol/L)	168	30.4% (51/168)	148	28.4% (42/148)	371	28.6% (106/371)
High serum creatinine^	168	3.6% (6/168)	148	4.1% (6/148)	370	6.8% (25/370)
High urate (uric acid)^	168	3.6% (6/168)	148	5.4% (8/148)	371	8.4% (31/371)
Low eGFR (<60 mL/min/1.73 m2) CKD-EPI formula	167	Low (≤5/167)	148	6.1% (9/148)	368	9.2% (34/368)
High ALT^	167	Low (≤5/167)	147	Low (≤5/147)	368	Low (≤5/368)
High AST^	168	4.8% (8/168)	148	Low (≤5/148)	371	Low (≤5/371)
High GGT^	168	14.3% (24/168)	148	12.8% (19/148)	371	12.4% (46/371)
High ALP^	168	5.4% (9/168)	148	4.1% (6/148)	371	4.6% (17/371)
Low serum albumin^	168	Low (≤5/168)	148	Low (≤5/148)	371	Low (≤5/371)
Abnormal TSH^	165	3.6% (6/165)	148	4.1% (6/148)	366	3.0% (11/366)
Hypothyroidism (high TSH and low/normal free T4)^	165	Low (≤5/165)	148	Low (≤5/148)	364	1.9% (7/364)
Hyperthyroidism (low TSH and high/normal free T3/T4)^	165	Low (≤5/165)	148	Low (≤5/148)	364	Low (≤5/364)

^ Reference intervals vary by sex and/or age.

Table A6-26. Summary of lipid concentrations and liver, kidney and thyroid function biomarker concentrations for residents of comparison communities, 2020.

	Alice Springs, NT						Dalby, Qld						Kiama and Shellharbour, NSW					
	N	Mean	SD	p25	Med	p75	N	Mean	SD	p25	Med	p75	N	Mean	SD	p25	Med	p75
Total cholesterol (mmol/L)	168	5.1	1.1	4.5	5.1	5.8	148	5.0	0.9	4.5	5.1	5.7	371	5.0	1.0	4.3	5.0	5.7
HDL cholesterol (mmol/L)	168	1.5	0.4	1.2	1.4	1.7	148	1.4	0.4	1.1	1.4	1.6	371	1.5	0.4	1.2	1.5	1.7
LDL cholesterol (mmol/L)	161	3.2	1.0	2.5	3.1	3.7	146	3.1	0.9	2.5	3.2	3.8	364	3.0	0.9	2.3	3.0	3.6
Total:HDL cholesterol ratio	168	3.7	1.2	2.9	3.4	4.3	148	3.8	1.1	3.0	3.6	4.4	371	3.5	0.9	2.8	3.4	4.1
Triglycerides (mmol/L)	168	1.8	1.2	1.0	1.5	2.3	148	1.8	1.1	1.1	1.4	2.2	371	1.7	1.0	1.1	1.5	2.1
Serum creatinine (umol/L)	168	71.8	15.5	60.9	70.4	80.9	148	74.5	18.0	63.0	72.6	82.3	370	75.2	18.4	62.6	72.5	83.1
Urate (uric acid) (mmol/L)	168	0.3	0.1	0.3	0.3	0.4	148	0.3	0.1	0.3	0.3	0.4	371	0.3	0.1	0.3	0.3	0.4
eGFR (mL/min/1.73 m2) CKD-EPI formula	167	90.5	16.7	77.9	91.9	102.0	148	88.3	17.3	79.9	89.4	98.6	368	84.5	17.4	73.9	86.5	94.9
ALT (U/L)	167	14.9	12.8	9.0	11.9	16.7	147	12.5	6.1	9.0	10.7	14.0	368	12.0	6.0	8.3	10.3	13.8
AST (U/L)	168	21.3	12.6	15.6	18.7	23.2	148	18.5	5.7	14.9	17.3	21.6	371	19.8	5.8	15.8	18.8	22.8
GGT (U/L)	168	27.9	27.0	13.7	19.2	29.2	148	27.5	30.3	13.1	18.4	28.4	371	27.3	32.0	14.2	20.0	28.9
ALP (U/L)	168	70.6	22.6	56.4	67.1	79.5	148	72.0	20.6	57.7	69.6	82.3	371	73.0	21.8	57.3	70.9	83.8
Serum albumin (g/L)	168	42.4	2.9	40.6	42.1	44.2	148	41.7	2.6	40.3	41.8	43.5	371	42.7	2.6	40.9	42.6	44.7
Total protein (g/L)	168	70.6	3.9	68.2	70.5	72.9	148	69.6	3.6	67.1	69.8	71.9	371	71.2	3.9	68.6	71.0	73.6
TSH (mIU/L)	165	1.7	0.8	1.1	1.5	2.1	148	1.5	0.8	1.0	1.3	1.9	366	1.6	1.0	1.0	1.4	1.9
Free T3 (pmol/L)	166	4.1	0.5	3.8	4.1	4.4	148	4.2	0.5	3.9	4.2	4.5	364	4.2	0.5	3.9	4.2	4.6
Free T4 (pmol/L)	166	11.9	1.3	11.0	11.8	12.7	148	11.8	1.4	11.0	11.6	12.3	365	12.1	1.3	11.2	11.9	12.9

N: sample size; SD: standard deviation; P25: 25th percentile; Med: median; P75: 75th percentile.

Table A6-27. Adjusted prevalence ratios of adverse lipid, liver, kidney and thyroid function biomarker concentrations per doubling in PFAS serum concentrations for residents of comparison communities, 2020.

	Alice Springs, NT		Dalby, Qld		Kiama and Shellharbour, NSW	
	N (cases) Comparison	PR‡ (95% CI)	N (cases) Comparison	PR‡ (95% CI)	N (cases) Comparison	PR‡ (95% CI)
High total cholesterol (>5.5 mmol/L)						
PFOS (total)	151 (51)	0.91 (0.72,1.16)	122 (41)	1.08 (0.82,1.42)	301 (103)	1.12 (0.95,1.31)
PFOS (branched isomers)	151 (51)	0.89 (0.65,1.22)	123 (41)	1.11 (0.81,1.53)	301 (103)	1.11 (0.93,1.33)
PFOA	151 (51)	1.18 (0.91,1.51)	123 (41)	0.97 (0.77,1.21)	301 (103)	1.18 (0.98,1.42)
PFHxS	151 (51)	0.96 (0.79,1.16)	123 (41)	1.10 (0.89,1.35)	301 (103)	1.21 (1.06,1.37)
Low HDL cholesterol^						
PFOS (total)	151 (15)	0.59 (0.36,0.94)	122 (17)	0.83 (0.48,1.44)	301 (16)	1.27 (0.83,1.94)
PFOS (branched isomers)	151 (15)	0.52 (0.26,1.02)	123 (17)	1.03 (0.53,2.03)	301 (16)	1.61 (0.84,3.06)
PFOA	151 (15)	0.73 (0.42,1.26)	123 (17)	0.98 (0.63,1.54)	301 (16)	1.34 (0.78,2.28)
PFHxS	151 (15)	0.52 (0.32,0.85)	123 (17)	1.15 (0.73,1.80)	301 (16)	1.24 (0.80,1.93)
High LDL cholesterol (>4 mmol/L)						
PFOS (total)	144 (24)	0.77 (0.51,1.14)	121 (22)	1.14 (0.74,1.76)	295 (48)	1.36 (0.99,1.86)
PFOS (branched isomers)	144 (24)	0.76 (0.43,1.32)	122 (22)	1.23 (0.78,1.94)	295 (48)	1.39 (1.02,1.89)
PFOA	144 (24)	0.84 (0.53,1.36)	122 (22)	1.22 (0.85,1.76)	295 (48)	1.15 (0.83,1.61)
PFHxS	144 (24)	0.82 (0.59,1.13)	122 (22)	1.05 (0.76,1.45)	295 (48)	1.40 (1.12,1.75)
High total:HDL cholesterol ratio (>4.5)						
PFOS (total)	151 (33)	0.72 (0.52,1.00)	122 (30)	1.29 (0.90,1.87)	301 (42)	1.11 (0.88,1.41)
PFOS (branched isomers)	151 (33)	0.79 (0.52,1.21)	123 (30)	1.61 (1.12,2.32)	301 (42)	1.37 (1.03,1.84)
PFOA	151 (33)	0.98 (0.63,1.52)	123 (30)	1.29 (0.95,1.75)	301 (42)	1.16 (0.84,1.60)
PFHxS	151 (33)	0.73 (0.55,0.95)	123 (30)	1.14 (0.85,1.54)	301 (42)	1.21 (0.96,1.52)
High triglycerides (>2 mmol/L)						
PFOS (total)	151 (48)	0.90 (0.70,1.16)	122 (30)	1.14 (0.85,1.52)	301 (87)	0.99 (0.85,1.16)
PFOS (branched isomers)	151 (48)	0.91 (0.68,1.23)	123 (30)	1.29 (0.94,1.77)	301 (87)	1.03 (0.85,1.24)
PFOA	151 (48)	0.88 (0.66,1.17)	123 (30)	1.32 (1.02,1.69)	301 (87)	1.03 (0.84,1.26)
PFHxS	151 (48)	0.91 (0.76,1.10)	123 (30)	1.15 (0.87,1.51)	301 (87)	1.03 (0.88,1.22)
High serum creatinine^						
PFOS (total)	151 (5)	2.32 (0.56,9.59)	122 (4)	0.70 (0.26,1.86)	301 (22)	1.28 (0.83,1.96)
PFOS (branched isomers)	151 (5)	2.70 (0.79,9.20)	123 (4)	0.58 (0.25,1.36)	301 (22)	1.46 (0.89,2.38)
PFOA	151 (5)	1.41 (0.47,4.28)	123 (4)	1.15 (0.13,9.84)	301 (22)	1.87 (1.11,3.14)
PFHxS	151 (5)	1.45 (0.74,2.83)	123 (4)	0.57 (0.30,1.07)	301 (22)	1.50 (1.06,2.12)
High urate (uric acid)^						
PFOS (total)	151 (4)	1.71 (0.91,3.23)	122 (8)	2.20 (1.13,4.27)[S]	301 (22)	2.17 (1.46,3.22)[S]
PFOS (branched isomers)	151 (4)	1.07 (0.49,2.34)	123 (8)	2.60 (1.36,4.96)	301 (22)	2.59 (1.70,3.96)[S#]

	Alice Springs, NT		Dalby, Qld		Kiama and Shellharbour, NSW	
	N (cases) Comparison	PR‡ (95% CI)	N (cases) Comparison	PR‡ (95% CI)	N (cases) Comparison	PR‡ (95% CI)
PFOA	151 (4)	1.32 (0.69,2.50)	123 (8)	1.75 (1.04,2.95)	301 (22)	2.36 (1.44,3.88)
PFHxS	151 (4)	1.17 (0.64,2.14)	123 (8)	1.38 (0.83,2.27)	301 (22)	1.82 (1.37,2.43)[S]
Low eGFR (<60 mL/min/1.73 m2) CKD-EPI formula						
PFOS (total)	151 (3)	1.09 (0.32,3.71)	122 (7)	1.43 (0.41,5.00)	300 (25)	1.50 (1.02,2.20)
PFOS (branched isomers)	151 (3)	1.47 (0.27,8.05)	123 (7)	1.32 (0.43,4.04)	300 (25)	1.65 (1.06,2.57)[S]
PFOA	151 (3)	0.44 (0.11,1.73)	123 (7)	1.30 (0.32,5.24)	300 (25)	1.99 (1.24,3.18)
PFHxS	151 (3)	1.17 (0.44,3.13)	123 (7)	0.71 (0.42,1.21)	300 (25)	1.52 (1.13,2.02)
High ALT^						
PFOS (total)	151 (2)	0.33 (0.12,0.94)	146 (1)	NC	300 (3)	1.51 (0.48,4.69)
PFOS (branched isomers)	151 (2)	0.12 (0.01,1.46)	122 (0)	NC	300 (3)	2.74 (0.58,12.91)
PFOA	151 (2)	0.40 (0.12,1.30)	122 (0)	NC	300 (3)	4.81 (0.58,40.13)
PFHxS	151 (2)	0.40 (0.15,1.07)	122 (0)	NC	300 (3)	1.24 (0.64,2.41)
High AST^						
PFOS (total)	151 (6)	1.21 (0.43,3.42)	122 (2)	1.58 (0.96,2.62)[S]	301 (4)	NC
PFOS (branched isomers)	151 (6)	0.82 (0.28,2.38)	123 (2)	2.55 (1.29,5.07)	301 (4)	NC
PFOA	151 (6)	1.23 (0.47,3.17)	123 (2)	1.44 (0.99,2.10)[S]	301 (4)	NC
PFHxS	151 (6)	1.19 (0.63,2.26)	123 (2)	4.32 (1.39,13.36)	301 (4)	NC
High GGT^						
PFOS (total)	151 (22)	0.80 (0.57,1.14)	122 (13)	1.21 (0.78,1.88)	301 (38)	1.02 (0.76,1.36)
PFOS (branched isomers)	151 (22)	0.82 (0.53,1.28)	123 (13)	1.45 (0.86,2.43)	301 (38)	1.19 (0.83,1.69)
PFOA	151 (22)	0.99 (0.63,1.55)	123 (13)	1.05 (0.66,1.68)	301 (38)	1.25 (0.85,1.84)
PFHxS	151 (22)	0.86 (0.63,1.17)	123 (13)	1.12 (0.78,1.61)	301 (38)	1.14 (0.86,1.50)
High ALP^						
PFOS (total)	151 (8)	NC	122 (4)	0.67 (0.38,1.20)	301 (12)	0.93 (0.53,1.62)
PFOS (branched isomers)	151 (8)	NC	123 (4)	0.54 (0.24,1.23)[S]	301 (12)	0.92 (0.48,1.78)
PFOA	151 (8)	NC	123 (4)	0.33 (0.14,0.75)	301 (12)	0.83 (0.46,1.50)
PFHxS	151 (8)	NC	123 (4)	0.87 (0.51,1.50)	301 (12)	0.86 (0.53,1.38)
Abnormal TSH^						
PFOS (total)	151 (4)	1.14 (0.35,3.74)	122 (4)	0.11 (0.03,0.36)	301 (1)	1.17 (0.75,1.80)
PFOS (branched isomers)	151 (4)	1.07 (0.29,3.98)	123 (4)	0.11 (0.02,0.54)	301 (1)	2.37 (1.38,4.04)
PFOA	151 (4)	0.45 (0.11,1.81)	123 (4)	0.35 (0.17,0.75)[S]	301 (1)	0.88 (0.65,1.18)
PFHxS	151 (4)	0.94 (0.41,2.14)	123 (4)	0.16 (0.07,0.37)	301 (1)	3.90 (2.55,5.96)[S]

N: sample size; PR: prevalence ratio; NC: convergence not achieved; S: significantly different to the estimated effect in the corresponding exposed community (p<0.05).

‡ Adjusted for age, sex, level of education and gross household annual income. Age was modelled using a restricted cubic spline with 3 knots.

^ Reference intervals vary by sex and age.
# Estimated assuming an independence (rather than exchangeable) within-cluster correlation structure and cluster-robust standard errors.

Table A6-28. Differences in mean lipid, liver, kidney and thyroid function biomarker concentrations per doubling in PFAS serum concentrations for residents of comparison communities, 2020.

	Alice Springs, NT		Dalby, Qld		Kiama and Shellharbour, NSW	
	N Comparison	Difference[¶] (95% CI)	N Comparison	Difference[¶] (95% CI)	N Comparison	Difference[¶] (95% CI)
Total cholesterol (mmol/L)						
PFOS (total)	151	−0.00 (−0.19,0.18)	122	0.20 (0.00,0.39)	301	0.15 (0.04,0.26)
PFOS (branched isomers)	151	0.01 (−0.24,0.25)	123	0.22 (−0.01,0.45)	301	0.11 (−0.01,0.24)
PFOA	151	0.10 (−0.12,0.33)	123	0.06 (−0.11,0.23)	301	0.20 (0.08,0.32)
PFHxS	151	−0.00 (−0.15,0.15)	123	0.15 (−0.00,0.30)	301	0.14 (0.05,0.24)
HDL cholesterol (mmol/L)						
PFOS (total)	151	0.02 (−0.04,0.08)	122	0.01 (−0.05,0.07)	301	0.03 (−0.01,0.07)
PFOS (branched isomers)	151	−0.00 (−0.08,0.08)	123	−0.01 (−0.09,0.06)	301	−0.01 (−0.06,0.04)
PFOA	151	0.05 (−0.02,0.12)	123	−0.00 (−0.07,0.06)	301	0.06 (0.02,0.10)
PFHxS	151	0.02 (−0.03,0.08)	123	−0.00 (−0.06,0.05)	301	0.00 (−0.03,0.03)
LDL cholesterol (mmol/L)						
PFOS (total)	144	0.00 (−0.18,0.19)	121	0.19 (0.01,0.37)	295	0.13 (0.03,0.24)
PFOS (branched isomers)	144	0.05 (−0.19,0.29)	122	0.23 (0.02,0.43)	295	0.14 (0.02,0.26)
PFOA	144	0.10 (−0.13,0.32)	122	0.07 (−0.10,0.24)	295	0.10 (−0.02,0.23)
PFHxS	144	−0.03 (−0.18,0.12)	122	0.12 (−0.03,0.27)	295	0.14 (0.05,0.23)
Total:HDL cholesterol ratio						
PFOS (total)	151	−0.12 (−0.32,0.08)	122	0.12 (−0.07,0.32)	301	0.04 (−0.06,0.13)
PFOS (branched isomers)	151	−0.10 (−0.34,0.13)	123	0.22 (0.01,0.43)	301	0.11 (−0.01,0.23)
PFOA	151	−0.06 (−0.28,0.17)	123	0.08 (−0.09,0.25)	301	0.02 (−0.10,0.14)[S]
PFHxS	151	−0.15 (−0.31,0.01)	123	0.15 (−0.04,0.34)	301	0.11 (0.03,0.19)
Triglycerides (mmol/L)						
PFOS (total)	151	−0.14 (−0.36,0.08)	122	0.09 (−0.05,0.23)	301	−0.02 (−0.10,0.07)
PFOS (branched isomers)	151	−0.15 (−0.39,0.09)	123	0.16 (−0.01,0.33)	301	0.01 (−0.10,0.12)
PFOA	151	−0.08 (−0.32,0.15)	123	0.05 (−0.08,0.18)	301	0.04 (−0.08,0.17)
PFHxS	151	−0.09 (−0.24,0.06)	123	0.15 (−0.04,0.34)	301	0.07 (−0.01,0.16)
Serum creatinine (umol/L)						
PFOS (total)	151	2.88 (0.77,4.98)[S]	122	−0.79 (−5.46,3.89)	301	1.66 (0.01,3.31)
PFOS (branched isomers)	151	3.81 (1.02,6.59)[S]	123	−1.13 (−6.52,4.26)	301	2.78 (0.67,4.90)[S]
PFOA	151	0.68 (−1.74,3.09)	123	−1.19 (−6.25,3.88)	301	3.52 (0.90,6.13)[S]
PFHxS	151	1.37 (−0.14,2.88)[S]	123	−1.63 (−5.61,2.35)	301	1.72 (−0.27,3.72)
Urate (uric acid) (mmol/L)						
PFOS (total)	151	0.01 (−0.01,0.02)	122	0.01 (−0.01,0.02)	301	0.01 (−0.00,0.02)
PFOS (branched isomers)	151	0.00 (−0.01,0.02)	123	0.01 (−0.01,0.03)	301	0.02 (0.01,0.03)

	Alice Springs, NT		Dalby, Qld		Kiama and Shellharbour, NSW	
	N Comparison	Difference[¶] (95% CI)	N Comparison	Difference[¶] (95% CI)	N Comparison	Difference[¶] (95% CI)
PFOA	151	0.01 (−0.01,0.02)	123	0.01 (−0.00,0.03)	301	0.01 (0.00,0.02)
PFHxS	151	0.00 (−0.01,0.01)	123	0.00 (−0.01,0.01)	301	0.01 (0.00,0.02)
eGFR (mL/min/1.73 m2) CKD-EPI formula						
PFOS (total)	151	−2.78 (−4.80,−0.75)[S]	122	−0.36 (-3.55,2.83)	300	−1.37 (−2.89,0.16)
PFOS (branched isomers)	151	-3.54 (−6.08,−1.01)[S]	123	−0.33 (-3.97,3.30)	300	−2.50 (−4.24,−0.76)[S]
PFOA	151	−0.96 (-3.42,1.50)	123	0.27 (−2.97,3.51)	300	−2.97 (−4.99,−0.96)[S]
PFHxS	151	−1.28 (−2.79,0.23)[S]	123	0.39 (−2.29,3.07)	300	−1.35 (−2.85,0.15)
ALT (U/L)						
PFOS (total)	151	−1.92 (−4.51,0.67)	121	−0.41 (−1.93,1.10)	300	0.24 (−0.44,0.91)
PFOS (branched isomers)	151	−2.75 (−5.58,0.07)	122	−0.11 (−1.86,1.63)	300	0.58 (−0.28,1.44)
PFOA	151	−1.07 (−2.61,0.47)	122	−0.38 (−1.89,1.14)	300	0.87 (−0.15,1.88)
PFHxS	151	−1.36 (−2.95,0.23)	122	−0.09 (−1.34,1.15)	300	0.38 (−0.15,0.91)
AST (U/L)						
PFOS (total)	151	−0.51 (-3.00,1.98)	122	0.26 (−0.69,1.22)	301	0.42 (−0.22,1.07)
PFOS (branched isomers)	151	−1.08 (-3.77,1.62)	123	0.31 (−0.83,1.45)	301	0.53 (−0.28,1.33)
PFOA	151	0.59 (−0.87,2.06)	123	0.64 (−0.23,1.52)	301	0.98 (0.14,1.81)
PFHxS	151	0.03 (−1.61,1.66)	123	0.48 (−0.48,1.45)	301	0.79 (0.22,1.36)[S]
GGT (U/L)						
PFOS (total)	151	-3.69 (-9.50,2.12)	122	2.31 (−0.97,5.59)	301	−1.83 (−6.35,2.69)
PFOS (branched isomers)	151	-3.98 (−11.24,3.28)	123	2.83 (−1.36,7.02)	301	−0.92 (−6.18,4.34)
PFOA	151	−0.26 (−4.33,3.81)	123	−1.20 (−4.06,1.65)	301	0.24 (−4.40,4.87)
PFHxS	151	−1.87 (−6.36,2.61)	123	1.81 (−0.81,4.42)	301	−1.21 (−4.31,1.89)
ALP (U/L)						
PFOS (total)	151	−2.72 (−6.83,1.38)	122	−1.23 (−4.98,2.52)	301	0.44 (−2.11,2.98)
PFOS (branched isomers)	151	−1.30 (−6.01,3.41)	123	−0.85 (−5.30,3.60)	301	0.55 (−2.55,3.64)
PFOA	151	−1.02 (−5.45,3.42)	123	−1.14 (−4.91,2.64)	301	0.61 (−2.80,4.03)
PFHxS	151	−0.83 (-3.69,2.02)	123	−0.41 (-3.43,2.61)	301	1.07 (−0.95,3.10)
Serum albumin (g/L)						
PFOS (total)	151	0.07 (−0.43,0.58)	122	0.97 (0.47,1.47)[S]	301	0.30 (0.04,0.57)
PFOS (branched isomers)	151	−0.09 (−0.68,0.50)	123	1.15 (0.59,1.72)[S]	301	0.30 (−0.03,0.63)
PFOA	151	0.42 (−0.13,0.98)	123	0.42 (0.02,0.82)	301	0.35 (−0.03,0.72)
PFHxS	151	0.19 (−0.21,0.59)	123	0.65 (0.26,1.04)[S]	301	0.28 (0.01,0.56)
Total protein (g/L)						
PFOS (total)	151	0.15 (−0.46,0.77)	122	1.29 (0.41,2.17)	301	0.39 (−0.01,0.80)
PFOS (branched isomers)	151	0.14 (−0.69,0.97)	123	1.36 (0.46,2.27)	301	0.49 (0.01,0.97)

	Alice Springs, NT		Dalby, Qld		Kiama and Shellharbour, NSW	
	N Comparison	Difference¶ (95% CI)	N Comparison	Difference¶ (95% CI)	N Comparison	Difference¶ (95% CI)
PFOA	151	0.49 (−0.17,1.15)	123	0.52 (−0.25,1.29)	301	0.43 (−0.08,0.94)
PFHxS	151	0.15 (−0.32,0.63)	123	1.07 (0.38,1.75)	301	0.31 (−0.07,0.68)
TSH (mIU/L)						
PFOS (total)	148	0.07 (−0.07,0.21)	122	0.10 (−0.06,0.27)	297	0.10 (0.00,0.20)
PFOS (branched isomers)	148	0.07 (−0.09,0.24)	123	0.13 (−0.02,0.29)	297	0.09 (−0.04,0.23)
PFOA	148	0.07 (−0.08,0.23)	123	0.18 (0.05,0.31)	297	0.12 (−0.02,0.26)
PFHxS	148	−0.01 (−0.11,0.10)	123	0.05 (−0.09,0.19)	297	0.04 (−0.05,0.13)
Free T3 (pmol/L)						
PFOS (total)	149	0.02 (−0.06,0.10)	122	0.09 (0.01,0.17)	295	0.01 (−0.05,0.06)
PFOS (branched isomers)	149	0.05 (−0.04,0.15)	123	0.14 (0.05,0.23)S	295	0.05 (−0.02,0.11)
PFOA	149	0.04 (−0.07,0.14)	123	0.01 (−0.08,0.10)	295	−0.00 (−0.07,0.06)
PFHxS	149	0.05 (−0.02,0.11)	123	0.07 (0.00,0.14)S	295	0.02 (−0.03,0.07)
Free T4 (pmol/L)						
PFOS (total)	149	0.03 (−0.18,0.24)	122	0.02 (−0.23,0.27)	296	−0.09 (−0.24,0.05)
PFOS (branched isomers)	149	0.02 (−0.21,0.25)	123	0.10 (−0.16,0.36)	296	0.01 (−0.18,0.20)
PFOA	149	−0.03 (−0.31,0.24)	123	0.12 (−0.06,0.30)	296	−0.08 (−0.25,0.09)
PFHxS	149	0.05 (−0.12,0.22)	123	0.03 (−0.17,0.23)	296	−0.03 (−0.16,0.10)

N: sample size; NC: convergence not achieved; S: significantly different to the estimated effect in the corresponding exposed community ($p<0.05$).

¶ Adjusted for age, sex, level of education and gross household annual income. Age was modelled using a restricted cubic spline with 3 knots.

Estimated assuming an independence (rather than exchangeable) within-cluster correlation structure and cluster-robust standard errors.

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