Queensland Alliance for Environmental Health Sciences
23 February 2024

THE UNIVERSITY OF QUEENSLAND
AUSTRALIA
CREATE CHANGE

Change of Per- and Poly- Fluoroalkyl Substances (PFAS) Serum Concentration in Avalon ARFFS Staff after Exposure Control

Acknowledgments

The project team would like to acknowledge the assistance, involvement, and contribution of all Aviation Rescue and Firefighting Services (ARFFS) operational and retired staff and Avalon airport staff who participated in the Avalon testings. We acknowledge that the contamination exposure has been a concerning time for staff and appreciate their engagement and communication with the project team and the support they have provided to their fellow staff throughout this time. We also acknowledge the consultation process with the employer groups and other representatives from Avalon airport who have worked closely with the project team. We also thank the staff at Sullivan and Nicolaides Pathology and Sonic Healthcare. The Queensland Alliance for Environmental Health Sciences at the University of Queensland is co-funded by Queensland Health.

Suggested Citation:

Nilsson S, Kay M, King L, Marrington S, Mueller J. Change of Per- and Poly- Fluoroalkyl Substances (PFAS) Serum Concentration in Avalon ARFFS Staff after Exposure Control. The University of Queensland, 2024.

Direct Enquiries to:

Dr Sandra Nilsson
Queensland Alliance for Environmental Health Sciences (QAEHS)
PACE Building
20 Cornwall St, Woolloongabba, Qld 4102
Email qaehsadmin@uq.edu.au
Web www.qaehs.centre.uq.edu.au
Centre phone +61 7 344 32443

Executive Summary

This report follows our previous report “Evaluation of Per- and Poly- Fluoroalkyl Substances (PFAS) Exposure to Avalon ARFFS Staff”.

Following detection of per- and poly-fluoroalkyl substances (PFAS) contamination in the mains water at Avalon Airport in October 2022, Airservices Australia invited Queensland Alliance for Environmental Health Sciences (QAEHS) to assist with a study with the aim of better understanding the Avalon Aviation Rescue Fire Fighting Service (ARFFS) staff exposure to PFAS. This included providing blood testing services for Airservices Australia’s ARFFS staff (current and former) who were concerned about potential PFAS exposure at Avalon. Avalon ARFFS staff initially provided blood samples between October 2022-February 2023. Approximately nine months later, in August 2023, follow up blood testing was offered.

The specific aims of this report were to

1) Determine how PFAS blood concentrations have changed over time in Airservices ARFFS staff (including contractors) at Avalon following exposure control that was implemented after the identification of PFAS contamination of the mains water.
2) Assess if blood or plasma donations have been helpful in speeding up the elimination of PFAS.

In total, 29 ARFFS provided a blood sample at both the initial and follow up testing, completed a questionnaire where they provided information about work history and blood/plasma donation, and consented for the use of their data for this assessment. The time between the two blood tests ranged from 8 to 11 months. The sum of PFOA, PFHxS PFHpS and PFOS concentration decreased in all participants who confirmed that they worked at the Avalon station between the two blood tests, with an average decrease of 32%. This is equivalent to a 38% annual decrease and is significantly faster compared to annual decrease in the general Australian population (12%/year) observed over the last five years, estimated from pooled serum samples of adults (over the age of 16). Overall, PFAS serum concentrations decreased in both those who were blood/plasma donors and those who were not. This suggests that PFAS exposure has been reduced for the participants. However, only five participants who currently worked at Avalon had not donated any blood/plasma and this limits any definite conclusion regarding any potential ongoing exposure. The decrease of PFAS serum concentration was associated with plasma donation, where greater number of plasma donations was associated with a greater decrease in PFAS serum concentration. This provides evidence that the elimination of PFAS can be increased, and that blood donation can be an effective treatment to reduce PFAS serum concentrations.

Abbreviations

AFFF	*Aqueous Film Forming Foam*
ARFF	*Aviation rescue and firefighting (service)*
ARFFS	*Aviation Rescue Fire Fighting Service*
PFAS	*Per- and Poly- fluoroalkyl substances*
PFOA	*Perfluorooctanoic acid*
PFHxS	*Perfluorohexanesulfonic acid*
PFHpS	*Perfluoroheptanesulfonic acid*
PFOS	*Perfluorooctanesulfonic acid*
QAEHS	*Queensland Alliance For Environmental Health Sciences*
QC/QA	*Quality Control and Quality Assurance*

Contents

1. Introduction

Airservices Australia ("Airservices") is an Australian Government-owned corporation responsible for air traffic control and related aviation services for the Australian aviation industry. This includes the provision of Aviation Rescue and Firefighting Services (ARFFS) at major civilian airports around Australia. Airservices began providing ARFF services at Avalon in 2005.

Historical storage and use of aqueous film forming foam (AFFF), particularly for firefighting training, has been the main source of PFAS contamination at Airservices' facilities. Although AFFF is not currently in use, historical environmental contamination may continue to pose a risk of potential new exposure routes, such as contaminated water sources. In October 2022, as part of a routine site contamination assessment testing, PFAS concentrations higher than the water guideline values [1] were found in the mains water at Avalon Airport.

PFAS was detected in the mains water, which was used for the drinking/potable water supply for Airservices facilities at Avalon Airport. In response, Airservices arranged an alternative water supply for their staff at Avalon and undertook a series of other exposure mitigation measures including a deep clean of the facilities and washing and flushing of the fire trucks. Equipment that could not be cleaned (e.g., washing machines, some firefighting equipment such as face masks and hoses) were replaced.

As part of the response, Airservices invited QAEHS to assist with a study aimed at better understanding the PFAS exposure of staff working at Avalon ARFFS. This included providing blood testing services for Airservices ARFFS staff at Avalon and searching for evidence to assist in identifying when the exposure to PFAS via drinking water may have begun. That investigation was reported previously [2] and is summarised in **Section 1.2** in this current report.

ARFFS staff were provided with the opportunity to have a follow up blood test approximately 8-12 months after their initial blood test. Continued monitoring of PFAS serum concentrations helps to provide an understanding of whether the measures being taken to mitigate the exposure (i.e., the deep clean and establishment of new water supply system) had been effective in removing the source of the elevated exposure. PFAS have long elimination half-lives of 5-9 years, which is equivalent to a 7-13% annual decrease [3]. This percent change is in line with analytical variability of the PFAS analysis [4]. Thus, a follow up blood test within less than one year may not be able to measure a decrease in concentration. However, the follow up blood tests will be able to provide information whether PFAS serum concentrations are increasing due to ongoing elevated exposure.

This report summarises the findings of the follow-up blood testing. The specific aims of the report were to;

1) Determine how PFAS blood concentrations have changed over time in Airservices ARFFS staff (including contractors) at Avalon following exposure control that was implemented after the identification of PFAS contamination of the mains water.
2) Assess if blood or plasma donations have been helpful in speeding up the elimination of PFAS.

1.1 Background PFAS Information

PFAS, is a collective term used for several classes of chemicals which have been used in consumer products and industrial applications since the 1950s. Perfluorinated substances have all hydrogen atoms on the carbon chain substituted by fluorine atoms, while polyfluorinated substances are only partially fluorinated and have some carbons bound to hydrogen [5]. Many PFAS are biologically persistent and can accumulate in the blood serum of individuals who are exposed. This report is focused on four PFAS: PFOA, PFHxS, PFHpS and PFOS, which are all perfluorinated substances (**Figure 1**).

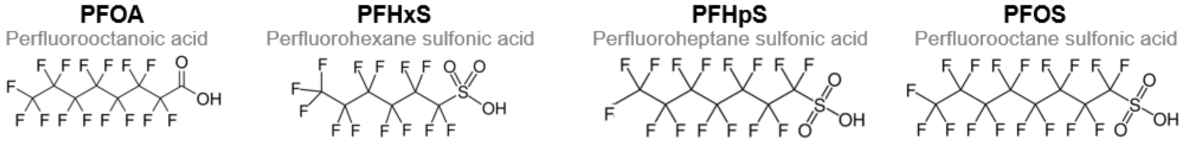

Figure 1: *Chemical structure of PFOA, PFHxS, PFHpS and PFOS.*

The unique physico-chemical properties of PFAS led to their use in AFFF, where they are especially efficient at smothering hydrocarbon-fuel fires [6]. The repeated use of AFFF, especially during fire training exercises, has led not only to widespread environmental PFAS contamination but also to the increased (occupational) exposure of firefighters to these chemicals [7].

The general population is exposed to PFAS through multiple different routes, including the use of consumer products, food and drinking water [8]. As a result, PFAS are detected in serum samples taken from members of the public who have has no occupational exposure to PFAS. Since 2002, QAEHS has conducted approximately biennial evaluations of the blood serum concentrations of PFAS in pooled samples of a general Australian population [9-11] (**Appendix I, A1.3)**. The pooled samples have allowed the documentation of changes in PFAS serum concentration in the Australian general population over time. The data demonstrate a decline in the concentrations of the most prominent PFAS (i.e., PFOA, PFHxS and PFOS) in the Australian population over the last two decades (**Figure 2**, only PFOS is shown). These datasets present important baseline values for the evaluation of PFAS in exposed populations and hence serve as a reference.

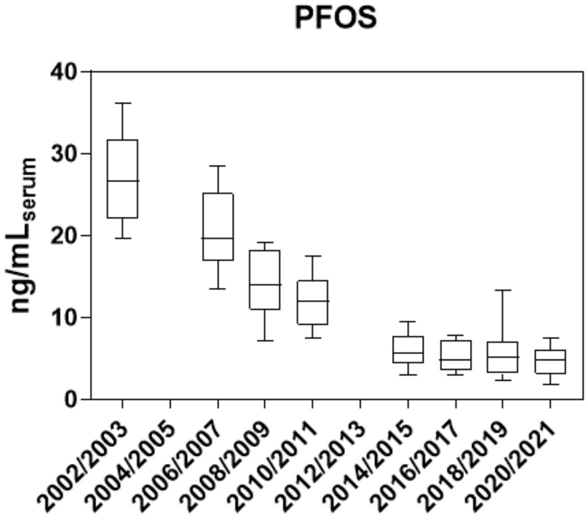

Figure 2*: Time-trend of PFOS serum concentrations in pooled samples from adults (>16 years) of the general Australian population. The lines in the boxes indicate median concentrations. The outside of the boxes represents the 25th and 75th percentiles, and the whiskers minimum and maximum concentrations.*

1.2 Overview of the Initial Avalon Testing

As a response to the detection of PFAS in the drinking water at Avalon Airport in October 2023, Airservices commissioned QAEHS to provide blood testing services for Airservices ARFFS staff, as well as Airport staff who had concerns relating to possible exposure to PFAS. QAEHS also used existing information from the PFAS database, available from previous and ongoing studies (the National Health and Medical Research Council (NHMRC) and Airservices Exposure Studies), to help to identify when the exposure to PFAS-impacted mains water began at Avalon Airport.

A total of 65 individuals, including 40 ARFFS and 25 Airport staff, provided an initial blood sample for analysis between October 2022 and January 2023. Of these, 25 ARFFS, consented to the use of their data for further data analysis which enabled assessments of the PFAS exposure trends.

The majority of these 25 participants had concentrations of PFHxS, PFHpS and PFOS that were close to, or higher than concentrations found in the general Australian population. PFOA concentrations were similar to the concentrations found in the general population. Of the 25 participants, 22 had provided a blood sample in at least one of our previous PFAS studies. The majority of the participants showed an increase in concentration of all the assessed PFAS (PFOA, PFHxS, PFHpS and PFOS) when compared to their previous blood sample.

To determine when the increase in PFAS exposure occurred, we reviewed our PFAS data base and identified information about PFAS exposure at Avalon. We identified a subset of ARFFS staff (n=7), who in addition to having provided blood samples in the initial Avalon testing following the detection of PFAS contamination of the water supply (2022-2023), had previous blood levels measured in our previous studies in 2021 and 2019 and had confirmed in the associated questionnaires that they worked at Avalon at that time. This provided a unique opportunity to assess the change in PFAS serum concentration over time.

Median blood concentrations of PFOA, PFHxS, PFHpS and PFOS for the three blood tests taken in 2019, 2021 and 2022/23 are shown in **Figure 3**. A clear increase in concentration of the assessed PFAS was observed between blood tests taken in 2021 and 2022/23. This increase suggests that the participants experienced an increase in exposure between 2021 and 2022/23.

Between 2018/19 and 2021, median concentrations of PFAS for those who had worked at Avalon had decreased. However, the rate of decrease for the Avalon ARFFS staff was found to be slower than the rate of decrease for ARFFS staff who did not work at Avalon during the same timeframe, when reviewing our existing database. Although the sample size is too small for any definitive conclusions regarding this observation, it is possible that Avalon ARFFS staff experienced ongoing low exposure sometime after their 2019 blood sample collection, and/or very recent elevated exposure just prior to the 2021 blood test.

In summary, the findings of this study confirmed that exposure of Avalon ARFFS staff to PFAS contaminated mains water resulted in an elevation of their PFAS serum levels.

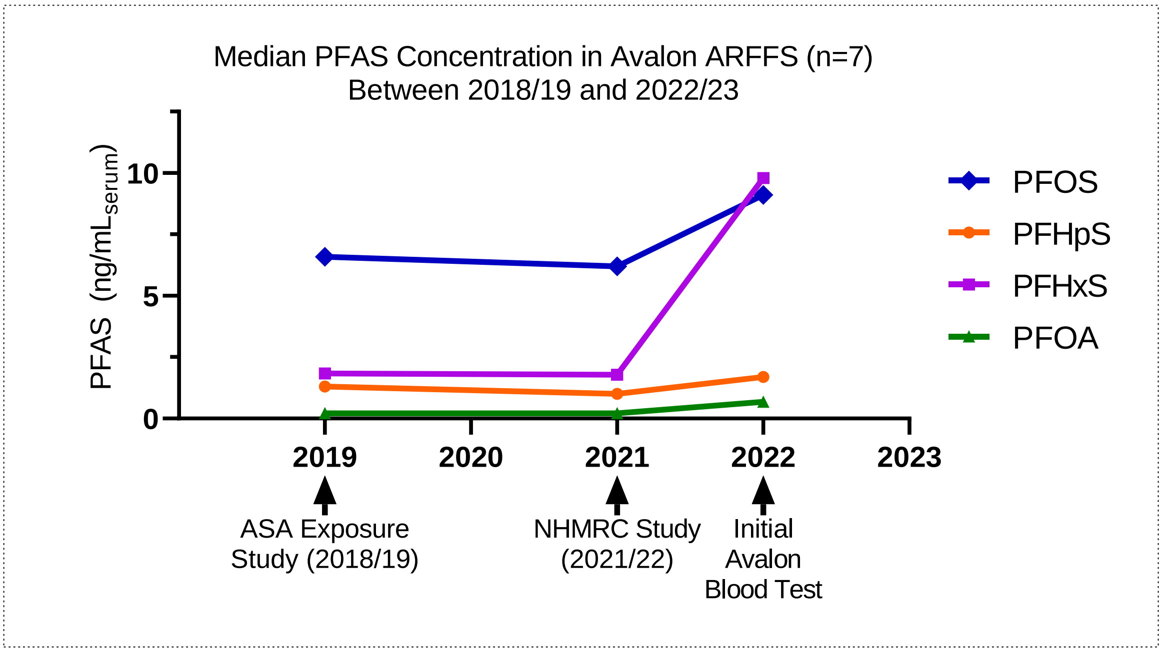

***Figure 3**. Median concentrations of PFOS, PFHpS, PFHxS and PFOA among Avalon ARFFS staff (n=7) between 2018/19 and 2022/23. The ARFFS staff were assumed to have been employed at the Avalon station during the period assessed.*

2. Methods

2.1 Study Design and Ethical Clearance

All data and material generated in the provision of this investigation were kept secure and confidential. Ethical approval was provided by the University of Queensland Human Research Ethics Committee (2020_3923)

2.2 PFAS Blood Testing for Avalon Staff

Airservices Avalon ARFFS staff (including contractors) who had previously provided a blood sample at the initial Avalon testing between October 2022 and February 2023 were offered a follow up blood test through QAEHS approximately 9 months following the initial testing. Between August 2023 and November 2023, 31 ARFFS staff provided a follow-up blood sample. Blood samples (3 SST tubes per participant) were collected by Sonic Healthcare/ Sullivan Nicolaides Pathology (SNP) at a collection clinic. All samples were sent to SNP in Brisbane, where biochemical analyses were performed on one of three collected SST tubes. More information about the biochemical analysis is available in **Appendix I** (**Section A.1.1**). Participants were also asked to complete a questionnaire to provide information about work history, blood donation and medication. In total, 29 ARFFS staff completed the accompanying questionnaire and consented to QAEHS using their data for further assessment. The questionnaire is available in **Appendix III.**

PFAS analysis was conducted at QAEHS laboratories. Blood serum samples were analysed for 42 different PFAS (**Table A4, Appendix II**). For the purpose of this report, the focus is on the four dominant PFAS; PFOA, PFHxS, PFHpS and PFOS. The analysis showed good reproducibility of replicate analysis within our laboratory, and accurate measurements of standard reference materials. Furthermore, the QAEHS lab participates in an inter-laboratory comparison study (AMAP) three times per year, and consistently passes acceptable criteria (**Table A4, Appendix II**). A report of individual PFAS results were provided to the participants approximately 1-2 months following the collection of the blood sample.

2.3 Data Analysis

To assess the change over time, the percent change (total and annual) in PFAS concentration was calculated between the initial and follow-up blood sample for each participant. The sum concentration of PFOA, PFHxS, PFHpS and PFOS ($\sum_4$PFAS) was used to assess change for simplicity. Change was also calculated for each PFAS separately. Due to the uncertainties associated with low concentrations close to the detection limits, change was not calculated where concentrations were <1.0 ng/mL in both samples. Most participants had PFHpS concentrations below 1.0 ng/mL. Thus, change was only calculated separately for PFOA, PFHxS and PFOS. To understand the exposure to PFAS at the Avalon station, QAEHS assessed the change in the PFAS blood concentrations over time for the ARFFS staff participants who confirmed in the questionnaire that they had worked at Avalon in 2023, i.e., during the time assessed (n=21).

To assess if blood or plasma donations have been helpful in speeding up the reduction of PFAS serum concentrations, all participants who provided information about blood donation were included in the assessment (n=29). The absolute percent decrease of PFAS between the two blood tests was used to assess change. The relationship between change in PFAS serum concentration (absolute percent decrease, continuous) and blood/plasma donations (number of blood/plasma donations, continuous) was assessed using multiple linear regression and was adjusted for gender (male, female), age (continuous), time between blood tests (days, continuous), and initial PFAS concentration (background vs elevated). Individuals were considered to have elevated concentrations of PFAS if they had either PFOA, PFHxS, PFHpS or PFOS concentrations above the estimated 95th percentile concentration of the general Australian population of the same age range. How these levels are estimated is described further in **Appendix I (Section A.1.3).**

For comparison, the annual percent change in PFAS serum concentration was also estimated in the general Australian population. This change was estimated from the average PFAS serum concentrations of pooled samples collected from adults (16 and over). Data from the three most recent collections (2018/19, 2020/21 and 2022/23) were included in the calculations to reflect recent rate of change. It is important to note that these averages include different individuals at each collection period. More information about the PFAS serum concentrations and annual change in the general Australian population is available in **Appendix I (Section A.1.3).**

3. Results and Discussion

3.1 Change in PFAS Serum Concentrations

The detection frequency and central tendencies of all PFAS analysed for are presented in **Table A5, Appendix II**. This report focused on PFOA, PFHxS, PFHpS and PFOS. Of the 29 participants who provided a blood sample at both sampling points and consented to the use of their data. The initial median/mean serum concentrations were 1.8/1.9 ng/mL (PFOA), 9.8/12 ng/mL (PFHxS), 0.66/1.2 ng/mL (PFHpS), 8.7/17 ng/mL (PFOS). Compared to the general Australian population, 86 % of the participants had elevated levels of at least one PFAS at the initial blood test. The median/mean PFAS levels were lower at the second blood test; 1.1/1.4 ng/mL (PFOA), 6.3/8.4 ng/mL (PFHxS), 0.47/0.95 ng/mL (PFHpS) and 5.9/12 ng/mL (PFOS). Although the PFAS serum concentrations were lower, 83% of the participants still had elevated levels of at least one PFAS, compared to the general Australian population.

Among the 29 participants, 21 reported that they were employed at Avalon station in 2023 (i.e. during the time assessed in this study) in the questionnaire. Other participants reported that they currently work at other stations, or that they did not hold a position at Airservices in 2023.

The individual change in PFAS serum concentrations was calculated for the 21 participants who were employed at Avalon station in 2023 to understand if the exposure to PFAS related to the mains water contamination had been reduced. The sum of PFOA, PFHxS, PFHpS and PFOS serum concentration decreased in all participants from Avalon. The individual decrease ranged from 4% to 57%, equivalent to a 5%-68% annual decrease.

These calculations reveal a trend for the sum of PFOA, PFHxS, PFHpS and PFOS serum concentrations among the participants who have worked at Avalon station in the last year to decrease. This suggests that the PFAS exposure has been reduced for these participants. It is important to note that many of these participants from Avalon were blood donors (n=16). Donation is known to speed up the elimination of PFAS and could potentially mask ongoing exposure [3]. The average decrease among the Avalon participants who were not donors (n=5) was slower compared to donors (n=16) with an annual decrease of 18% vs 45% of the sum of PFOA, PFHxS, PFHpS and PFOS. A faster PFAS elimination in donors is expected and demonstrates that donation can reduce PFAS serum concentrations, but there is currently no available data for comparison. The mean annual decrease in PFAS serum concentrations (sum of PFOA, PFHxS, PFHpS and PFOS) in the few participants (n=5) that were not donors is consistent with the annual decrease found in the general population (i.e., ~12 % decrease per year). The results from these five participants suggest that there was no recent elevated exposure to PFAS for those participants. However, it is important to note that the rate of change in the general population is estimated from average concentrations from different individuals over the time assessed. A direct comparison of the rate of change described for the general population with that observed for an individual level should be made with caution. Furthermore, is important to note that this is based on only five participants and over a short timeframe.

In addition to assessing the change in the sum PFOA, PFHxS, PFHpS and PFOS serum concentration, the change for PFOA, PFHxS and PFOS was also assessed separately (where concentrations were above 1.0 ng/mL). Decreases in PFOA and PFHxS concentrations were observed in all participants, with an average decrease of 34 % for both PFOA and PFHxS. PFOS serum concentrations decreased in all participants except for one. The participant who did not show a decrease in PFOS was not a blood/plasma donor. Overall, PFOS serum concentrations decreased 32% (37% among blood/plasma donors, and 17% among non-blood/plasma donors).

This study did not aim to measure a ‘*decrease*’ in the concentrations of PFAS found in individuals because of the short time frame for the follow up sample and the analytical uncertainties and the long elimination half-lives. These limitations are discussed further in section **3.3 Study Limitations.** Nevertheless, the follow up sample allows us to assess whether there are any ‘*increases*’ in PFAS serum concentrations which would suggest ongoing/new exposure. The limited data show that there is no evidence of any elevated exposure in the participants.

3.2 Change in PFAS Serum Concentrations and Blood/plasma Donation

The change in PFAS serum concentration was assessed in relation to blood/plasma donation in the 29 participants who filled in the questionnaire, regardless of if they currently worked at Avalon or not. Of these, 66% (n=19) confirmed that they had donated plasma at least once between the two blood tests while 16% reported that, in addition to plasma, they had also donated blood. The number of plasma/blood donations ranged from 1 to 15 times over the course of 8-11 months between the two blood tests. There was a positive association between serum level decrease and number of donations, where greater decreases in PFAS serum concentration can be observed in those with a higher number of donations (**Figure 4**).

The relationship between blood/plasma donation and the decrease in PFAS serum concentration was assessed and the outcomes are presented in **Table A6, Appendix II**. Overall, the greater the number of donations, the larger the decrease in PFAS serum concentrations. For each additional plasma donation, the sum of PFOA, PFHxS, PFHpS and PFOS serum concentrations decreased by 4.1% (95% confidence interval (95CI) of 2.9%, 5.2%). The specific decrease of PFOA, PFHxS and PFOS was 3.7% (95CI 2.2-5.1%), 4.5% (95CI 3.3-5%) and 3.6% (95CI 1.8-5.5%) respectively, for each additional plasma donation.

Associations between a reduction in PFAS serum concentrations and plasma/blood donation, as well as lower PFAS serum concentrations among blood donors have been reported in other studies, including the previous Airservices exposure studies [3, 7, 12-14]. In the blood, PFAS bind to serum proteins [15]. As these proteins are removed through blood or plasma donations, the bound PFAS would also be removed. This can explain the decreased serum concentration. The current assessment provides evidence that PFAS elimination can be enhanced with blood/plasma donations. Such donations could be suggested as a treatment for highly exposed individuals who wish to reduce their PFAS serum concentration.

It is important to note that there is background exposure to PFAS in our daily lives via exposures to products, food, dust, air, and water (unrelated to AFFF use). This background exposure may contribute to PFAS in the body and potentially result in an apparent increase in serum concentrations for example in individuals that managed to decrease PFAS serum concentrations to very low levels with the aid of blood or plasma donations.

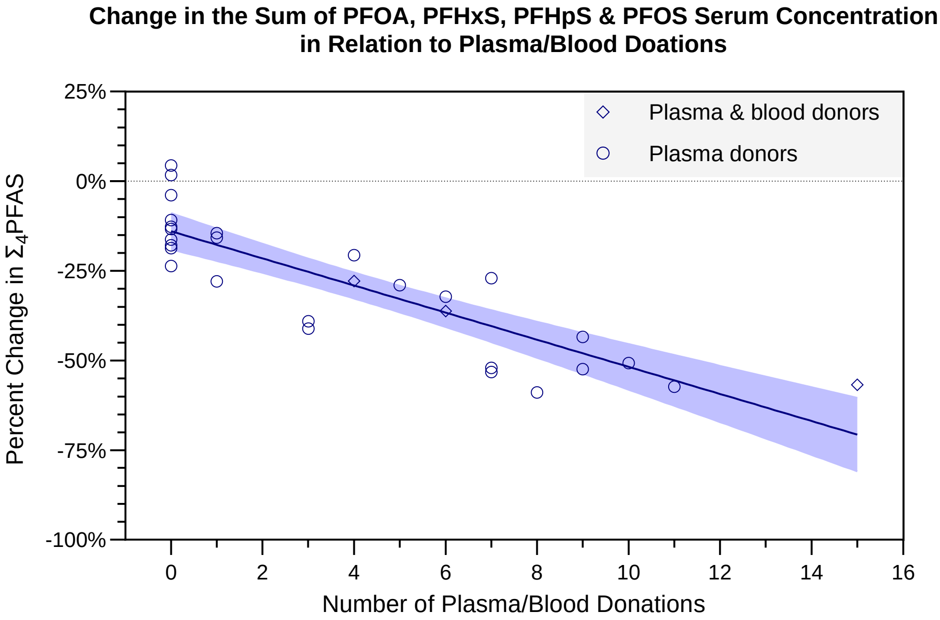

Figure 4. *Change (percent) of the sum of PFOA, PFHxS, PFHpS and PFOS serum concentration (*$\sum_4$*PFAS) in 29 study participants who donated plasma or both blood and plasma between 0-15 times over the course of 8-11 months. The blue line shows the unadjusted trend and the highlighted blue area represent the 95% confidence interval.*

3.3 Study Limitations

Blood donation may mask any evidence of ongoing exposure. The majority of participants who were still working at the Avalon station during the time assessed were blood/plasma donors, thus limiting the data available for assessment of any ongoing exposure at Avalon to only five individuals who confirmed they had not donated any blood between the two blood tests. It is also worth noting that due to the long elimination half-life of PFAS in non-blood donors (5-9 years, equivalent to a 7-13% annual decrease [3]), the expected decrease in the 8-11 months between the blood tests could be influenced by analytical uncertainties of the PFAS analysis [4]. Although overall decreases in PFAS serum concentrations were found among non-blood donors, the limited data hinders any definite conclusions of potential ongoing exposure. Follow up blood testing is recommended for non-blood/plasma donors.

3.4 Future Studies

Continued blood testing will be offered to Avalon ARFFS staff who are interested in monitoring of their levels of PFAS. Continued monitoring of PFAS serum concentrations, especially in those who are not donating blood or plasma, helps to provide an understanding of whether the measures being taken to mitigate the exposure (i.e., the deep clean and establishment of new water supply system) have been effective.

4. Conclusion

As a response to the detection of PFAS in the mains water at Avalon Airport, Airservices commissioned QAEHS to provide blood testing services for Airservices ARFFS. Avalon ARFFS staff (both current and former staff) provided two blood samples, 8-11 months apart.

With reference to the study aims; the findings were:

1) Determine how PFAS blood concentrations have changed over time in Airservices ARFFS staff (including contractors) at Avalon following exposure control that was implemented after the identification of PFAS contamination of the mains water.

Decreases in the sum of PFOA, PFHxS, PFHpS and PFOS concentration were observed among all participants who confirmed that they worked at Avalon during the time assessed (n=21). Decreases in PFOA and PFHxS levels were found in all participants. PFOS levels decreased in all but one participant, who was not a blood donor. On average, the sum of PFOA, PFHxS, PFHpS and PFOS concentration decreased 32% between the two blood tests, equivalent to a 38% annual decrease. Decreasing trends in PFAS serum concentrations suggests that the ongoing elevated PFAS exposure has been reduced to the participants. It is important to note that the limited number of non-blood/plasma donors, together with the analytical uncertainty, hinders any definite conclusions regarding potential ongoing exposure.

2) Assess if blood or plasma donations have been helpful in speeding up the elimination of PFAS.

A greater decrease in PFAS serum concentrations was observed in plasma/blood donors in comparison to those who were not donating blood/plasma. The decrease in PFAS serum concentrations significantly increased with the number of plasma/blood donations. These findings add to the evidence that the elimination of PFAS can be sped up, and blood/plasma donations may be considered as a treatment for exposed individuals who wish to reduce their PFAS serum concentrations.

5. References

1. NHMRC, *Australian Drinking Water Guidelines Paper 6 National Water Quality Management Strategy*. 2011, National Resource Management Ministerial Council, Commonwealth of Australia: Canberra.

2. Nilsson, S., et al., *Evaluation of Per- and Poly- Fluoroalkyl Substances (PFAS) Exposure to Avalon ARFFS Staff*. 2023, The University of Queensland.

3. Nilsson, S., et al., *Serum concentration trends and apparent half-lives of per- and polyfluoroalkyl substances (PFAS) in Australian firefighters.* International Journal of Hygiene and Environmental Health, 2022. **246**: p. 114040.

4. Nilsson, S., et al., *Analytical uncertainties in a longitudinal study – A case study assessing serum levels of per- and poly-fluoroalkyl substances (PFAS).* International Journal of Hygiene and Environmental Health, 2021. **238**: p. 113860.

5. Buck, R.C., et al., *Perfluoroalkyl and polyfluoroalkyl substances in the environment: terminology, classification, and origins.* Integrated environmental assessment and management, 2011. **7**(4): p. 513-541.

6. Moody, C.A. and J.A. Field, *Perfluorinated surfactants and the environmental implications of their use in fire-fighting foams.* Environmental science & technology, 2000. **34**(18): p. 3864-3870.

7. Rotander, A., et al., *Elevated levels of PFOS and PFHxS in firefighters exposed to aqueous film forming foam (AFFF).* Environment International, 2015. **82**: p. 28-34.

8. Sunderland, E.M., et al., *A review of the pathways of human exposure to poly- and perfluoroalkyl substances (PFASs) and present understanding of health effects.* Journal of Exposure Science & Environmental Epidemiology, 2019. **29**(2): p. 131-147.

9. Toms, L.M.L., et al., *Per- and polyfluoroalkyl substances (PFAS) in Australia: Current levels and estimated population reference values for selected compounds.* International Journal of Hygiene and Environmental Health, 2019.

10. Toms, L.M.L., et al., *Decline in perfluorooctane sulfonate and perfluorooctanoate serum concentrations in an Australian population from 2002 to 2011.* Environment International, 2014. **71**: p. 74-80.

11. Toms, L.-M.L., et al., *Polyfluoroalkyl chemicals in pooled blood serum from infants, children, and adults in Australia.* Environmental Science & Technology, 2009. **43**(11): p. 4194-4199.

12. Gasiorowski, R., et al., *Effect of Plasma and Blood Donations on Levels of Perfluoroalkyl and Polyfluoroalkyl Substances in Firefighters in Australia: A Randomized Clinical Trial.* JAMA Network Open, 2022. **5**(4): p. e226257-e226257.

13. Nilsson, S., et al., *Evaluation of per- and poly- fluoroalkyl substances (PFASs) in Airservices Australia's Aviation Rescue Fire Fighting Service (ARFFS) Staff – 2018/2019*. 2020.

14. Rotander, A., et al., *Evaluation of perfluoroalkyl acids (PFAAs) in Airservices Australia's Aviation Rescue and Fire Fighting (ARFF) staff*. 2014: Canberra, ACT, Australia.

15. Han, X., et al., *Binding of perfluorooctanoic acid to rat and human plasma proteins.* Chemical Research in Toxicology, 2003. **16**(6): p. 775-781.

16. Aylward, L.L., et al., *Population variation in biomonitoring data for persistent organic pollutants (POPs): An examination of multiple population-based datasets for application to Australian pooled biomonitoring data.* Environment International, 2014. **68**: p. 127-138.

Appendices

Appendix I. Further Descriptions

A.1.1. Biochemical Analysis

The biochemical analysis included a lipid profile, serum protein analysis, a thyroid function test, and analysis of biochemical markers for liver and kidney function (**Table A1, Appendix I**). The biochemical markers were included in the study because they are potential health markers associated with PFAS exposure and/or because they may be confounders that influence PFAS retention in the serum. QAEHS sent a letter to each participant within 2-3 weeks of the collection of the blood samples with their initial individual biochemistry results. These letters were reviewed by a medical doctor. Abnormal biochemical results were flagged with advice provided to the participants that they arrange further follow up. Participants were encouraged to provide the results to their usual health provider so that the results could be part of their health record.

Table A1. *Biochemical markers included in the blood test.*

Biochemical endpoints	Biochemical markers
Lipid profile *Biomarkers for cardiovascular disease, metabolic effects*	Cholesterol, Triglycerides, high density lipoprotein (HDL), low density lipoprotein (LDL)
Thyroid function tests *Biomarkers for thyroid disease*	Thyroid Stimulating Hormone (TSH), Free Thyroxine (T4), Free Triiodothyronine (T3)
Liver function *Biomarkers for liver disease*	Alanine Aminotransferase (ALT), gamma-glutamyl transferase (GGT), Alkaline Phosphatase (ALP), Total Bilrubin
Kidney function *Biomarkers for kidney disease*	Urate (Uric acid), creatinine, estimated Glomerular Filtration Rate (eGFR)
Serum proteins *Provide binding sites for PFAS in blood*	Globulin, Albumin, total protein

A1.2 Statistical Terms Used in This Report

Mean: The mean is a value to describe central tendency. It is calculated by adding all individual values and dividing the sum by the number of values.

Median: The median describes the central tendency of the data set. It is the middle value of all sets of data arranged in the order lowest to highest (or vice versa). In the population, half of the population has values below the median while the other half has values above the median.

Percentiles: The spread around the median is often described by percentiles. These are determined by arranging all sets of data in the order lowest to highest. **Percentiles** is a measurement at which the percentage of the total values are at, or below this measurement.

A.1.3. Human Biomonitoring in the General Australian Population

Since 2002, QAEHS has conducted cross-sectional collection of surplus pathology serum samples from the general Australian population every two years. Samples are pooled according to age and gender. Pooling of samples mean that serum from 100 people of the same gender and age group is mixed into a single sample. A total of four pools per age and gender group are collected each round. The concentration measured in the pooled sample is an estimate of the mean concentration in the sampled group. These pooled sample results are the only data available to indicate exposure concentrations for the general Australian population. These data have been corresponding well with estimates of mean concentrations in the general population in the USA, which were based on measurements of individual samples [9].

A.1.3.1 Estimation of the 95th Percentile

Since the data for the general populations stem from pooled samples, only a mean PFAS concentration is available. To account for population variation, the variation of PFAS in the general Australian population was assumed to have a similar variation to the United States. The mean:95th percentile concentration ratios for a given age group, based on population variation from available datasets from the National Health and Nutrition Examination Survey (NHANES) in the United States, was used to estimate the 95th percentile for PFOA, PFHxS and PFOS in the Australian population [9, 16]. NHANES does not measure PFHpS concentrations in the general population, therefore the mean of the population variation for PFOA, PFHxS and PFOS was applied to derive the 95th percentile for PFHpS. While this adds some uncertainty to the 95th percentile of PFHpS it still gives an indication of general population variation. **Table A2** presents the 95th percentile for PFOA, PFHxS, PFHpS and PFOS from the sample collection in 2023.

Table A2 *shows the estimated 95th percentile concentrations of PFOA, PFHxS, PFHpS and PFOS (ng/mL) found in the general Australian population (2023).*

	PFOA	PFHxS	PFHpS	PFOS
Ages 16 – 30 years	**2.1 ng/mL**	**2.7 ng/mL**	**0.12 ng/mL**	**3.9 ng/mL**
Ages 31 – 45 years	**2.1 ng/mL**	**3.0 ng/mL**	**0.16 ng/mL**	**5.5 ng/mL**
Ages 46 – 60 years	**2.6 ng/mL**	**3.2 ng/mL**	**0.24 ng/mL**	**6.6 ng/mL**
Ages > 60 years	**3.4 ng/mL**	**5.0 ng/mL**	**0.40 ng/mL**	**11 ng/mL**

A.1.3.2 Estimation of the Rate of Change

In this report, the rate of change among ARFFS are assessed. For comparisons, we also estimated the rate of change in the general Australian population. To reflect the current rate of change, only the three most recent collections were used. The average PFAS serum concentrations from all pools consisting of individuals of the ages 16 and over were used to reflect the change among adults. These levels are shown in **Table A3.**

Table A3 *shows the average concentrations of PFOA, PFHxS, PFHpS and PFOS (ng/mL) found in adults of the general Australian population in 2018/19, 2020/21 and 2022/23, and the average annual change over this time.*

	PFOA	PFHxS	PFHpS	PFOS	∑$PFAS_4$[1]
2018/19	**1.8 ng/mL**	**1.9 ng/mL**	**0.18 ng/mL**	**5.2 ng/mL**	**9.0 ng/mL**
2020/21	**1.6 ng/mL**	**1.7 ng/mL**	**0.17 ng/mL**	**4.6 ng/mL**	**8.1 ng/mL**
2022/23	**1.2 ng/mL**	**1.3 ng/mL**	**0.10 ng/mL**	**2.8 ng/mL**	**5.4 ng/mL**
Average annual change	**-9%**	**-10%**	**-13%**	**-14%**	**-12%**

1. The sum of PFOA, PFHxS, PFHpS and PFOS

Appendix II: Additional Tables

Table A4. Quality Assurance/Quality Control Outcomes in follow up sample analysis; The coefficient of variation (CV) of inter- an intra- batch duplicate samples (n=4) & replicate sample (n=2), z-score of reference material samples (SRM 1957, n=2) and general score from interlaboratory comparison 2023 scheme.

	Duplicates	Replicates	Reference Material	AMAP 2023
PFAS	Average CV	CV	z-score	General Score
PFBA	n.a	n.a	n.a	100%
PFPeA	n.a	n.a	n.a	n.a
PFHxA	n.a	n.a	n.a	96%
PFHpA	n.a	n.a	n.a	81%
PFOA	9.2%	3.0%	-0.14	89%
PFNA	n.a	n.a	n.a	74%
PFDA	n.a	n.a	n.a	89%
PFUnDA	n.a	n.a	n.a	93%
PFDoDA	n.a	n.a	n.a	n.a
PFTriDA	n.a	n.a	n.a	n.a
PFTreDA	n.a	n.a	n.a	n.a
PFHxDA	n.a	n.a	n.a	n.a
PFODA	n.a	n.a	n.a	n.a
PFPrS	n.a	n.a	n.a	n.a
PFBS	n.a	n.a	n.a	96%
PFPeS	12%	n.a	n.a	n.a
PFHxS	2.1%	7.7%	-0.45	93%
PFHpS	8.8%	4.3%	n.a	100%
PFOS	3.8%	0.6%	0.64	100%
PFNS	n.a	n.a	n.a	n.a
PFDS	n.a	n.a	n.a	n.a
PFDoDS	n.a	n.a	n.a	n.a
FBSA	n.a	n.a	n.a	n.a
FHxSA	n.a	n.a	n.a	n.a
FOSA	n.a	n.a	n.a	n.a
N-Me FOSA	n.a	n.a	n.a	n.a
N-Et FOSA	n.a	n.a	n.a	n.a
FOSAA	n.a	n.a	n.a	n.a
N-Me FOSAA	n.a	n.a	n.a	n.a
N-Et FOSAA	n.a	n.a	n.a	n.a
N-Me FOSE	n.a	n.a	n.a	n.a
N-Et FOSE	n.a	n.a	n.a	n.a
4:2 FTS	n.a	n.a	n.a	n.a
6:2 FTS	n.a	n.a	n.a	n.a
8:2 FTS	n.a	n.a	n.a	n.a
10:2 FTS	n.a	n.a	n.a	n.a
8Cl-PFOS	n.a	n.a	n.a	n.a
PFECHS	n.a	n.a	n.a	n.a
GenX	n.a	n.a	n.a	n.a
ADONA	n.a	n.a	n.a	n.a
9Cl-F53B (9Cl-PF3ONS)	n.a	n.a	n.a	n.a
11Cl-F53B (11Cl-PF3OUdS)	n.a	n.a	n.a	n.a

n.a; not applicable (compound not detected/assessed)
CV; Coefficient of variance; Standard variation/mean
z-score; a statistical measurement describing a measurements relationship to the reference value, measured in terms of standard deviations from the reference value. Generally,
General score from AMAP 2023 interlaboratory study; 3x rounds 3x samples/round. General score is calculated according to the total points accumulated during the 2023 rounds. The general score is calculated according to the total of points accumulated on a maximal total of three points per results. The score is calculated according to z-score in absolute value, where Z-scores <+/-1 equals 3 points, z-scores between +/-1-2 equals 2 points. z-scores between +/-2-3 equals 1 points, and z scores >+/-3 equals 0 points.

Table A5*. List of all PFAS analysed for, method detection limits used for reporting results, detection frequency and the central tendency of PFAS concentrations in the 29 participants who provided blood samples in both the initial[1] and follow up[2] blood tests and consented to the use of data.*

PFAS*		Method Detection Limits	Detection Frequency		Median[3]		Mean (SD)[3]	
			Initial test	Follow up test	Initial test	Follow up test	Initial test	Follow up test
Perfluoroalkylcarboxylic acids	PFBA	<0.38	0%	0%	<0.38	<0.38	<0.38	<0.38
	PFPeA	<0.35	0%	0%	<0.35	<0.35	<0.35	<0.35
	PFHxA	<0.20	0%	35%	<0.20	<0.20	<0.20	<0.20
	PFHpA	<0.33	16%	0%	<0.33	<0.33	<0.33	<0.33
	PFOA	<0.37	100%	100%	1.8	1.1	1.9 (1.1)	1.4 (0.8)
	PFNA	<0.43	6%	3%	<0.43	<0.43	<0.43	<0.43
	PFDA	<0.43	3%	3%	<0.43	<0.43	<0.43	<0.43
	PFUnDA	<0.48	0%	0%	<0.48	<0.48	<0.48	<0.48
	PFDoDA	<0.43	0%	0%	<0.43	<0.43	<0.43	<0.43
	PFTriDA	<0.20	0%	0%	<0.20	<0.20	<0.20	<0.20
	PFTreDA	<0.23	0%	0%	<0.23	<0.23	<0.23	<0.23
	PFHxDA	<0.35	0%	0%	<0.35	<0.35	<0.35	<0.35
	PFODA	<0.18	0%	0%	<0.18	<0.18	<0.18	<0.18
Perfluoroalkylsulfonates	PFPrS	<0.25	0%	0%	<0.25	<0.25	<0.25	<0.25
	PFBS	<0.33	0%	0%	<0.33	<0.33	<0.33	<0.33
	PFPeS	<0.28	58%	16%	0.33	<0.28	0.46 (0.3)	<0.28
	PFHxS	<0.40	100%	100%	9.8	6.3	12 (11)	8.4 (9.5)
	PFHpS	<0.40	68%	52%	0.66	0.47	1.2 (1.6)	0.95 (1.3)
	PFOS	<0.30	100%	100%	8.7	5.9	17 (23)	12 (16)
	PFNS	<0.38	0%	0%	<0.38	<0.38	<0.38	<0.38
	PFDS	<0.40	0%	0%	<0.40	<0.40	<0.40	<0.40
	PFDoDS	<0.48	0%	0%	<0.48	<0.48	<0.48	<0.48
Perfluoroalkane sulfonamides	FBSA	<1.0	0%	0%	<1.0	<1.0	<1.0	<1.0
	FHxSA	<1.0	0%	0%	<1.0	<1.0	<1.0	<1.0
	FOSA	<1.0	0%	0%	<1.0	<1.0	<1.0	<1.0
	N-Me FOSA	<0.48	0%	0%	<0.48	<0.48	<0.48	<0.48
	N-Et FOSA	<0.35	0%	0%	<0.35	<0.35	<0.35	<0.35
	FOSAA	<0.45	0%	0%	<0.45	<0.45	<0.45	<0.45
	N-Me FOSAA	<0.45	0%	0%	<0.45	<0.45	<0.45	<0.45
	N-Et FOSAA	<0.43	0%	0%	<0.43	<0.43	<0.43	<0.43
	N-Me FOSE	<0.23	0%	0%	<0.23	<0.23	<0.23	<0.23
	N-Et FOSE	<0.40	0%	0%	<0.40	<0.40	<0.40	<0.40
Telomer Sulfonates	4:2 FTS	<0.30	0%	0%	<0.30	<0.30	<0.30	<0.30
	6:2 FTS	<0.60	0%	0%	<0.60	<0.60	<0.60	<0.60
	8:2 FTS	<0.43	0%	0%	<0.43	<0.43	<0.43	<0.43
	10:2 FTS	<0.20	0%	0%	<0.20	<0.20	<0.20	<0.20
Chlorinated PFOS	8Cl-PFOS	<0.25	0%	0%	<0.25	<0.25	<0.25	<0.25
Cyclic PFAS	PFECHS	<0.30	0%	0%	<0.30	<0.30	<0.30	<0.30
PFAS Replacement Compounds	GenX	<0.25	0%	0%	<0.25	<0.25	<0.25	<0.25
	ADONA	<0.25	0%	0%	<0.25	<0.25	<0.25	<0.25
	9Cl-F53B (9Cl-PF3ONS)	<0.25	0%	0%	<0.25	<0.25	<0.25	<0.25
	11Cl-F53B (11Cl-PF3OUdS)	<0.25	0%	0%	<0.25	<0.25	<0.25	<0.25

PFOS is presented as the total concentration of both linear and branched isomers. All other compounds are measured as the linear isomer concentration,

2. Initial blood testing was conducted October 2022-January 2023. Follow up blood testing was conducted July 2023-October 2024.

3. For summary data, below method detection limits (MDL) are treated as "MDL/√2"

***Table A6**. Adjusted[1] beta coefficient (decrease) of the multiple linear regression models assessing the effect of plasma/blood donation on the decrease of PFAS serum concentration. The beta coefficient represents the percent decrease per additional blood/plasma donation.*

	$\sum_4$PFAS		PFOA		PFHxS		PFOS	
	Decrease[1]	p-value	Decrease[1]	p-value	Decrease[1]	p-value	Decrease[1]	p-value
Each additional plasma donation[2]	4.1% (2.9%, 5.2%)	0.000	3.7% (2.2%, 5.1%)	0.000	4.5% (3.3%, 5.6%)	0.000	3.6% (1.8%, 5.5%)	0.000
Each additional plasma or blood donation[3]	3.7% (2.7%, 4.6%)	0.000	3.4% (2.2%, 4.6%)	0.000	4% (3.1%, 4.9%)	0.000	3.1% (1.6%, 4.6%)	0.000

$\sum_4$PFAS (PFOA, PFHxS, PFHpS, PFOS).
1; Adjusted for gender, age, initial PFAS concentration and number of days between blood tests.
2; This assessment does not include those participants who provided both blood and plasma (n=3), as no information was available on how many plasma donations they had provided.
3; This assessment did include all donors, both those who only provided plasma and those who reportedly donated both blood and plasma.

Appendix III: Questionnaire

The University of Queensland
Australia

Queensland Alliance for Enviornmental Health Sciences (QAEHS)

Participant Code	1	5	3	1

Below are a few questions about your work history, blood donation and your health. This information is helpful to better understand the results from the analysis of your blood sample. If there are any questions you would rather not answer, please leave them blank.

1. Please state your date of birth ___ ___ _ ___ ___ _ ___ ___ ___ ___

DD MM YYYY

2. Please provide details of your job assignments/employment below.

NOTE: If you completed the "PFAS Exposure Study" survey for Airservices in 2019, you only have to provide details about your job assignments/employment since 2019.

Have you ever held the following positions during your employment at Airservices Australia (or its predecessors)? If, YES, please write when and for what organisation?

Role	Duration	Timeframe	Employer	Where/location
EXAMPLE: Firefighter	*2 years*	*2019-2020*	*Airservices*	*Avalon*
	3 years	*2020-2023*	*RAAF*	*RAAF Amberley*

Role	Duration	Timeframe	Employer	Where/location
Senior Officer				
Officer				
Firefighter				
Instructor				
Emergency vehicle technician (EVT)				
Other (Please provide information under 'Employer')				

The University of Queensland
Brisbane Qld 4072 Australia
T 1800 370 760
M 0419 110 176
E PFASstudyUQ@uq.edu.au
W qaehs.centre.uq.edu.au/pfas-exposure-control
ABN: 63 942 912 684
CRICOS PROVIDER NUMBER 00025B

3. **Have you donated blood/plasma since your previous blood testing in late 2022/early 2023?** *(Circle one number only)*

Yes, Blood	1
Yes, Plasma	2
Yes, both blood and plasma	3
I have not donated blood or plasma	4

4. **How frequently have you donated blood/plasma since your previous blood testing in late 2022/early 2023?** *(Circle one number only)*

Less than once	1
Once	2
2 to 3 times	3
4 or more times	4
I have not donated blood or plasma	5

5. **How many times have you donated blood/plasma since your previous blood testing in late 2022/early 2023? This may be recorded in your blood donation records or app on your smartphone.**

How many times have you donated blood or plasma	☐
Don't know	2
I have not donated blood or plasma	3

6. **Are you currently taking any of the following medications?**

Indicate 'no' or 'yes' for each medication; If 'yes', please provide the details of the medication.

	No	Yes	If 'yes', what is the name of the medicine/s?
Medication for high cholesterol	1	2	______
Medication for gout	1	2	______
Medication for diabetes	1	2	______
Medication for epilepsy	1	2	______
Fluid tablets	1	2	______
Medication for thyroid problems	1	2	______
Chemotherapy	1	2	______

7. **How tall are you without shoes?**

To the nearest centimeter or inch

Height ______ *cm* OR ______ *feet* ______ *inches*

Don't know 1

8. **About how much do you weigh?**

In very little or no clothing and without shoes, to the nearest kilogram or pound

Weight ______ *kg* OR ______ *stone* ______ *pounds*

Don't know 1

Contact details

Dr Sandra Nilsson
E qaehsadmin@uq.edu.au
W https://qaehs.centre.uq.edu.au/ uq.edu.au