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PFAS INVESTIGATION AND MANAGEMENT PROGRAM

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RAAF BASE DARWIN

PFAS MANAGEMENT AREA PLAN

February 2025

ACKNOWLEDGEMENT OF COUNTRY

Defence acknowledges the Traditional Custodians of Country throughout Australia. Defence recognises their continuing connection to traditional lands and waters and would like to pay respect to their Elders both past and present.

Defence would also like to pay respect to the Aboriginal and Torres Strait Islander peoples who have contributed to the defence of Australia in times of peace and war.

ABOUT THIS DOCUMENT

This is the Defence PFAS Management Area Plan (PMAP) Revision 1 for RAAF Base Darwin.

This PMAP Revision replaces the PMAP for RAAF Base Darwin dated July 2019.

The purpose of this PMAP is to document Defence's plan to manage potential risks to human health and the environment from PFAS on and from RAAF Base Darwin. It provides an overview of the actions undertaken to date, ongoing and future.

Relevant state and local agencies have been consulted in the development of this document.

EXECUTIVE SUMMARY

In 2019 Defence published the Royal Australian Air Force (RAAF) Base Darwin PFAS Management Area Plan (2019 PMAP) for managing risks to human health and the environment from per- and poly-fluoroalkyl substances (PFAS) contamination associated with RAAF Base Darwin (the base) and surrounding areas.

Since the 2019 PMAP was developed, Defence has implemented parts of the plan and reassessed what is now needed for ongoing management of these contamination risks. This PMAP revision sets out the updated plan to manage risks to human health and the environment from exposure to PFAS contamination from the base.

Eleven PFAS source areas contribute to PFAS moving off the base, including two former fire training areas, four former fuel farms, a stockpile area, a former aviation rescue and firefighting station, a hangar, a former RAAF fire station, and a current fire training area. The PFAS source areas are shown on Figure C1 in Appendix C.

Detailed investigations and risk assessments were undertaken in 2018 to characterise the nature and extent of PFAS and assess the potential risks to human health and the environment. These included:

- RAAF Base Darwin Detailed Site Investigation – Per and Poly-fluoroalkyl Substances (PFAS) (Coffey, 2018a)
- RAAF Base Darwin Supplementary Detailed Site Investigation Report (Coffey, 2018c)
- RAAF Base Darwin Human Health Risk Assessment (Coffey, 2018b)
- RAAF Base Darwin Ecological Risk Assessment (Coffey, 2018d)

The investigations found that PFAS present in soils at source areas leaches into groundwater and surface water before moving into Rapid Creek, Sadgroves Creek and Ludmilla Creek.

The risk assessments (Coffey, 2018b and Coffey, 2018d) found potentially elevated PFAS exposure risks to the following human and ecological receptors. ***Elevated*** indicates that the estimated exposure is likely to exceed the Tolerable Daily Intake (TDI) and has a Hazard Index (HI) greater than 1.

Human Health receptors	Ecological receptors
Consumers of eggs from domestic poultry watered with PFAS-impacted bore water in the suburb of Ludmilla.	Aquatic invertebrates, amphibians and fish in impacted waters of Rapid Creek and Ludmilla Creek.
Consumers of aquatic biota (fish or crustaceans) from Rapid Creek or the upper reaches of Ludmilla Creek.	Birds and mammals that eat fish from Rapid Creek.
Base construction or maintenance workers in direct contact with PFAS impacted water in PFAS source areas.	Plants and animals in direct contact with soils in PFAS source areas.
	Birds and mammals that eat plants, invertebrates and reptiles from PFAS source areas.

In 2019, Defence identified and implemented risk management actions to reduce PFAS movement from the base and to minimise risk to humans and the environment. These actions were reviewed and updated based on the latest information and progress.

Risk Management Action	Description
Completed Actions	
Manage Wrapped Stockpile Area and identify long-term management.	The Wrapped Stockpiles have been treated and removed.
Reduce leaching from CFTA infrastructure	PFAS contained within the CFTA training pad leaches during rainfall. The concrete pad has been removed.
Limit personnel access to effluent tanks at the CFTA and implement PPE controls.	The concrete infrastructure at the CFTA has been removed and treated.
Investigate remediation options for PFAS soils in FFTA1, CFTA, FFF4, FFF6, Wrapped Stockpiles Area	Remediation action plans have been prepared (and delivered for FFTA1 and the Wrapped Stockpile Area) for these source areas.
Ongoing Actions	
Investigate drainage pathways to reduce PFAS movement in stormwater	PFAS moves off the base in the drainage network (open drains and underground pipes) into Rapid and Ludmilla Creeks.
Investigate remediation options for soils at FFF1 and Hangar 31	These source areas contain PFAS contamination that contributed to PFAS moving from the base, as well as impacting terrestrial ecological receptors.
Investigate remediation options for groundwater and/or soil at the Former ARFF Fire Station.	High concentrations of PFAS in soil and groundwater at the Former ARFF Fire Station leach and migrate to Rapid Creek.
Investigate groundwater remediation options at FFF4 and FFF6	PFAS in groundwater at FFF4 and FFF6 contributes a significant portion of the PFAS that migrates from the base.
Investigate remediation options for the former RAAF FS	PFAS concentrations in groundwater beneath the source area are changing and potentially increasing.
Implement remediation once remediation actions plans are developed	Following development of remediation action plans for managing PFAS, undertake remediation.
Support Environment Protection Authority (EPA) and Health advisories	The NT Department of Health issued health advisories to limit consumption of aquatic biota collected from Rapid Creek. Defence supports this by providing information on the latest PFAS monitoring information to NT Government.
Manage PFAS soil movements	If PFAS within soils in source areas is moved, PFAS may be spread to other areas and increase movement of PFAS from the base.
Manage excavations in source areas	PFAS in soils and shallow groundwater in source areas presents a risk to workers in excavations who may come into contact with the soils or groundwater.
Include PFAS controls when designing new infrastructure at the base	As there are many PFAS source areas on the base, there is the potential for overlap of construction activities to either disturb PFAS impacted soils or allow remediation as a part of capital works.

CONTENTS

GLOSSARY

AFFF	Aqueous Film Forming Foam
ARFF	Aviation Rescue and Fire Fighting
ASC NEPM	National Environment Protection (Assessment of Site Contamination) Measure, as amended 2013
Base	RAAF Base Darwin
CFTA	Current Fire Training Area
CSM	Conceptual Site Model
CSR	Contaminated Sites Register
DIA	Darwin International Airport
DSI	Detailed Site Investigation
Eco	Ecological
EPA	Environment Protection Authority
ERA	Ecological Risk Assessment
FFF	Former Fuel Farm
FFTA	Former Fire Training Area
HDPE	High-density Polyethylene
HH	Human health
HHRA	Human Health Risk Assessment
Management Area	The geographical area subject to Defence risk management actions. May include private or Defence owned detached properties beyond the boundaries of the base
NOAEL	No observed adverse effect level
NT	Northern Territory
Off-site	Off-base
OMP	Ongoing Monitoring Plan
OMR	Ongoing Monitoring Report
PFAS	Per- and poly-fluoroalkyl Substances
PFAS NEMP	PFAS National Environmental Management Plan
PFBS	Perfluorobutane sulfonic acid
PFHxA	Perfluorohexanoic acid
PFHxS	Perfluorohexane sulfonic acid
PFOA	Perfluorooctanoic acid
PFOS	Perfluorooctane sulfonic acid
FOSA	Perfluorooctane sulfonamide
PMAP	PFAS Management Action Plan
PPE	Personal protective equipment

RAAF	Royal Australian Air Force
RAAF FS	RAAF Fire Station
RAP	Remediation Action Plan
Risk management actions	Remediation and management actions to address potential or actual risks to receptors from PFAS contamination.
ROA	Remediation Options Assessment
Risk assessment(s)	The HHRA and/or ERA
SFARP	So Far as Reasonably Practicable
Source	A source can be primary or secondary. Primary sources are generally areas where AFFF was used or stored. Secondary sources may be an accumulation of contamination in the environment, such as in soil, sediments, or surface water bodies.
TDI	Tolerable daily intake
UST	Underground storage tank

Unless otherwise defined in this document, definitions provided in the PFAS NEMP, or the ASC NEPM apply.

1 INTRODUCTION

1.1 Background and purpose

In July 2019 Defence published the PFAS Management Area Plan (2019 PMAP) for Royal Australian Air Force (RAAF) Base Darwin (the base) for managing risks to human health and the environment from per- and poly-fluoroalkyl substances (PFAS) contamination associated with the base and surrounding areas.

Since the 2019 PMAP for the base was developed, Defence has implemented and completed parts of the plan, and reassessed what is now needed to best manage exposure to PFAS contamination.

This assessment considered:

- Remediation actions from the 2019 PMAP that have been implemented, and the effectiveness of these actions.
- The outcomes of the mass flux study and other additional studies in the Management Area which provide a detailed understanding of the mass of PFAS leaving the base.
- Whether potential risks to human health or environmental receptors from PFAS contamination have changed, based on data collected through the ongoing monitoring program and other studies.
- A review of factors such as changes to government policy, site conditions, site usage requirements, and scientific methodologies and technology.

This PMAP revision sets out the updated plan to manage risks to human health and the environment from exposure to PFAS contamination at and from the base.

Defence's So-Far-As-Reasonably-Practicable (SFARP) approach to managing risk means any action adopted (remediation or management) is proportionate to the risks to receptors (human health or the environment). In assessing what is 'reasonably practicable' Defence considers the technical (availability and suitability of any chosen remediation or management approach), logistical, financial and sustainability (considering environmental, economic and social sustainability outcomes) aspects of the action. An SFARP assessment applies to the whole base but is also evaluated on a source-by-source basis and is independently verified by Defence's appointed Technical Advisor.

This PMAP has been developed in accordance with the PFAS National Environmental Management Plan (PFAS NEMP), which provides nationally consistent environmental guidance and standards for managing PFAS contamination. It is also consistent with Defence estate, environmental, and PFAS-specific strategies and guidance.

PMAPs are reviewed and updated as required to account for changes in circumstances such as progress in management and remediation, new data, changes in legislation, guidelines and policy, and advances in scientific information.

1.2 Management priorities

Defence's approach to managing PFAS contamination to reduce exposure to human health and the environment is to undertake remediation so-far-as-reasonably-practicable (SFARP) to reduce the mass of PFAS moving off the site. Defence prioritises:

- Understanding the source-pathway-receptors to help minimise exposure to PFAS
- preventing or minimising migration of PFAS
- keeping the community informed.

1.3 Supporting information

The PMAP revision is based on information from a range of different investigations, human health and ecological risk assessments, and remediation activities. Details of these reports are provided in Appendix A.

The reports identified a range of elevated risks to receptors from exposure to PFAS, which are the focus of the risk management actions outlined in this document.

1.4 Limitations and assumptions

This document has been developed based on the information available at the time of preparation, and the following limitations and assumptions:

- The current legislative setting and guidance for the assessment of risks to receptors from PFAS contamination.
- The available remediation and management techniques and technologies that may be effectively deployed to manage the migration of PFAS at the base.
- The sampling of various media to monitor the behaviour of PFAS in the environment is often limited by climatic conditions, with significant seasonal variation between the wet and dry seasons limiting collection of samples at some locations.

The PMAP will be revised if new information (such as revised guidelines, regulatory requirements, site data or remedial techniques) becomes available and the characterisation of risk changes, requiring a revised management or remediation approach.

2 MANAGEMENT AREA

The PFAS Management Area comprises the base and surrounding areas, as shown on Figure C1 in Appendix C.

The base is located on the Stuart Highway approximately seven kilometres from the business centre of Darwin, adjacent to the suburbs of Winnellie, Ludmilla, Coconut Grove, Millner, Jingili, Moil, Anula, Malak, Marrara, the Narrows, Karama and the North Lakes Estate.

The base encompasses an area of 1,278 hectares bounded by McMillans Road and the Northlakes Estate/Marrara Sports Complex to the north, Amy Johnson Avenue to the east, Stuart Highway to the south and Bagot Road to the west. Darwin International Airport (DIA) occupies an area to the north of the base, with the land on which DIA sits managed independently from the Department of Defence.

The base is an operational joint civil-military airfield, with use of the runways and taxiways shared with DIA. The base has administrative, accommodation, recreational and operational support facilities as well as technical workshops, aircraft hardstands and aircraft pavements. In addition to civil aircraft operations, the airfield supports both Australian and international military aircraft operations. Aircraft movement areas (runways and taxiways) are utilised by both civilian air operations and Defence.

The Management Area includes the entirety of the base and the DIA portion of the airfield and extends off-base as summarised in Table 2-1 below. A plan of the Management Area is presented as Figure 2-1 over-page. The rationale for the extent of the PFAS Management Area was where PFAS had been measured in surface water and/or groundwater above human health or ecological criteria, and areas adjacent to the creeks where floodwaters may have deposited PFAS impacted sediments. Further information on the surface water and groundwater criteria referenced in Table 2-1 below is provided in the Detailed Site Investigation (DSI) (Coffey, 2018a).

Table 2-1. Off-base PFAS Management Area

Off-base Management Area

Northern extent:
• The stream valley of Rapid Creek including:
  o parts of the residential suburbs of Milner, Moil and Rapid Creek,
  o parklands and riparian zone extending into the suburbs of Rapid Creek and Alawa.
• A small portion of the sporting fields in the western part of the Marrara Sporting Complex.

Eastern extent: • No area beyond the eastern boundary of the base formed part of the PMAP area.
Southern extent: • Parts of the industrial suburb of Winnellie and the Darwin Showground, Charles Darwin National Park (to the south of Tiger Brennan Drive) • Sadgroves and Reichardt Creeks to their interface with Darwin Harbour.
Western extent: • Residential suburbs of Bagot and Ludmilla as well as the riparian zone along Ludmilla Creek to the interface with Beagle Gulf. • Vacant land to the north of the Bagot Community up to the boundary with the suburb of Coconut Grove, and west to the high-tide mark on Beagle Gulf • Part of the suburb of East Point where Ludmilla Creek discharges to Beagle Gulf

The base is connected to town water supply by Power and Water, and bore water is not used in the base operations. No changes in water supply for the base or surrounding areas have occurred since the preparation of DSI report (Coffey, 2018a).

Since the completion of the 2019 PMAP, some areas of the base have been redeveloped to support Defence capability, and the Defence residential housing areas in the west of the base have been removed. No land uses surrounding the base have materially changed in use or are planned to be changed.

The extent of the PFAS Management Area as defined in the 2019 PMAP remains valid. The rationale for inclusion of these off-base areas remains relevant for PFAS monitoring and management.

Information about the PFAS Management Area environmental setting, such as climate, topography, geology, hydrology and various other aspects is provided in the RAAF Darwin Supplementary Detailed Site Investigation (Coffey, 2018c).

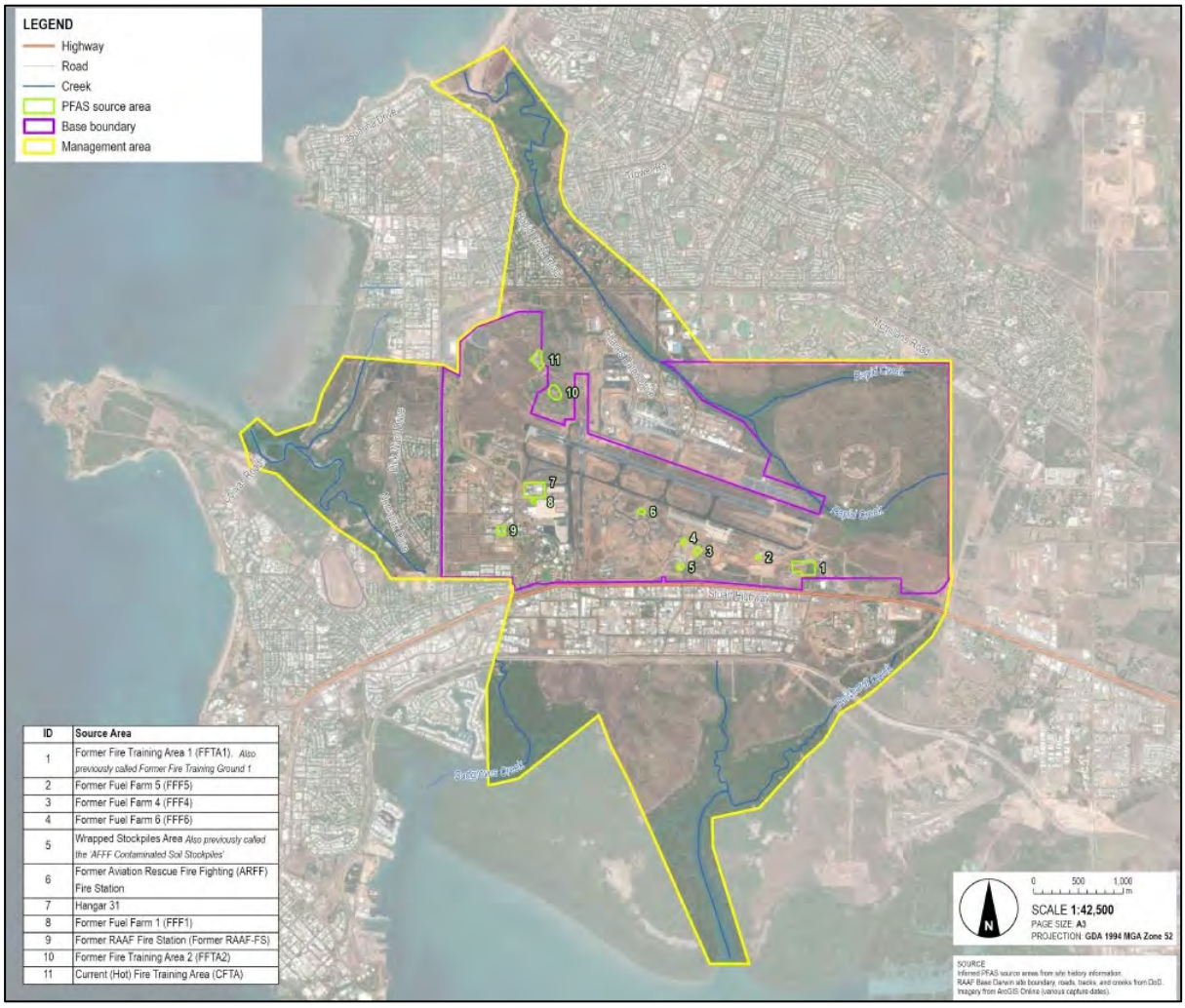

Figure 2-1. PFAS Management Area and PFAS source areas

3 EXTENT OF PFAS CONTAMINATION

This section provides an outline of the PFAS sources, transport pathways for migration of PFAS from a source area, and potential receptors such as humans and ecosystems that may be exposed to PFAS from the base.

This information is described as a conceptual site model (CSM), which is provided in Appendix B. As part of this PMAP revision, the CSM for the base and surrounding areas was reviewed for currency and updated. For more detailed information informing the CSM, refer to the reports listed in Appendix A.

The composition of PFAS on the base comprises approximately 91% (w/w) of Sum of perfluorooctane sulfonic acid (PFOS) + perfluorohexane sulfonic acid (PFHxS), with the remaining 9% comprising varying compositions of perfluorooctanoic acid (PFOA), Perfluorohexanoic acid (PFHxA), Perfluorobutane sulfonic acid (PFBS), Perfluorooctane sulfonamide (FOSA), and minor other PFAS compounds. For the purposes of this PMAP, where reference to PFAS is made, this refers to the Sum of PFOS+PFHxS, unless otherwise stated.

3.1 Source areas

Source areas can be primary or secondary. Primary sources are generally areas of PFAS contamination where aqueous film forming foam (AFFF) was used or stored, for example, a fire training area. Secondary source areas contain an accumulation of PFAS contamination in the environment, such as in soil, sediment, groundwater or surface water (such as drains or creeks), which has migrated from a primary source area.

The PFAS source areas that have been identified through previous investigations (Appendix A) are outlined in Table 3-1. Identified secondary sources of PFAS are outlined in Table 3-2.

Table 3-1. Known source areas of PFAS

Source area	Extent of PFAS contamination
Former Fire Training Area 1 (FFTA1) (CSR_NT_000039)	This PFAS source area (approximately 5,000 m^2) comprised a former fire training area where AFFF containing PFAS was sprayed onto fires and the ground during training activities between circa 1970s to 1990s. PFAS in this area was remediated in 2023 with PFAS impacted soils excavated and either removed from the site for thermal destruction or treated and reinstated in the area beneath a clay cap to reduce the mobility of PFAS. Approximately 16 kg of PFAS was remediated and approximately 5 kg of PFAS remains within soils at low concentrations around the perimeter of the remediation area. PFAS is present in shallow, perched groundwater during the wet season, and groundwater within the deeper siltstone aquifer throughout the year. Concentrations of PFAS in groundwater at this source area range between 7 to 73 µg/L.
Former Fuel Farm 5 (FFF5) (CSR_NT_000043)	This source area (approximately 2,500 m^2) was a former fuel farm where AFFF containing PFAS was used in a fire suppression system installed in the above-ground fuel tank storage area. PFAS is present in soils with an estimated mass of less than 1 kg present. Concentrations of PFAS in groundwater at this source area range between 1.7 to 76 µg/L.
Former Fuel Farm 4 (FFF4) (CSR_NT_000044)	This source area was a formerly an active fuel farm where PFAS containing AFFF containing PFAS was used in a fire suppression system installed in the above-ground fuel tank storage area. The fuel farm infrastructure has since been decommissioned.

Source area	Extent of PFAS contamination
	Approximately 4.9 kg of PFAS is present in soils, which is primarily present in the northern part of the source area. Concentrations of PFAS in groundwater in this source area range between 20 to 130 µg/L.
Former Fuel Farm 6 (FFF6) (CSR_NT_000045)	This source area was a formerly an active fuel farm where PFAS containing AFFF containing PFAS was used in a fire suppression system installed in the above-ground fuel tank storage area. The fuel farm infrastructure has since been decommissioned. Approximately 1.8 kg of PFAS is present in soils, which is primarily present in the northern portion of the source area. Concentrations of PFAS in groundwater in this source area range between 1 to 108 µg/L.
Wrapped Stockpile Area (CSR_NT_000047)	This source area (approximately 2,500 m^2) was remediated in 2023, as PFAS-contaminated soil stockpiles wrapped in plastic were removed from the area. The soils were treated to immobilise PFAS and reinstated into the FFTA1 remediation work area beneath the capping. Residual PFAS concentrations ranged up to 0.3 mg/kg in soils in a few isolated locations in the footprint of the area.
Former Aviation Rescue and Fire Fighting (ARFF) Station (CSR_NT_000040)	This source area (approximately 15,000 m^2) was the Former ARFF Station where AFFF containing PFAS was tested and drained from firefighting equipment onto the ground. Soil concentrations range up to 18 mg/kg, and more than 25 kg PFAS is estimated to remain. Concentrations of PFAS in groundwater range up to 345 µg/L.
Hangar 31 and Former Fuel Farm 1 (FFF1) (CSR_NT_000203 & CSR_NT_000205)	The Hangar 31 source area (approximately 15,000 m^2) comprises a large aircraft maintenance hangar that formerly contained an AFFF fire suppression system. Several foam deluge events were recorded at the hangar, with PFAS containing foams reportedly discharging from the hangar onto the soils surrounding the apron to the north and south. Shallow PFAS-impacted soils were removed in 2008 and stored at the Wrapped Stockpiles Area ahead of remediation completion in 2023. The FFF1 source area (approximately 3,500 m^2) was a former fuel farm where AFFF containing PFAS was used in a fire suppression system installed in the above-ground fuel tank storage area. Residual PFAS soil concentrations range up to 0.8 mg/kg, with an estimated 1 kg[1] of PFAS remaining in soils in these source areas and concentrations in groundwater up to 43 µg/L.
Former RAAF Fire Station (RAAF FS) (CSR_NT_000255)	This source area (approximately 5,000 m^2) was a former fire station where several fire trucks were stored and maintained but ceased operation in the 1990s. AFFF containing PFAS was tested and discharged from fire training equipment onto the ground. Soil PFAS concentrations range up to 18 mg/kg, with an estimated mass of 2.5 kg[1]. Concentrations of PFAS in groundwater range between 0.5 and 48 µg/L. PFAS concentrations in water in underground stormwater drains at the source area range from 0.02 µg/L to 10.3 µg/L. The variability in concentrations is considered to reflect the differences between stormwater flow conditions (0.02 to 0.04 µg/L) where the PFAS in the pipes is being diluted by upstream stormwater, and baseflow conditions (5.4 to 10.3 µg/L) which is indicative of PFAS impacted groundwater infiltrating into the pipes.
Current Fire Training Area (CFTA) (CSR_NT_000038)	This source area (approximately 4,500 m^2) was used for fire training activities from the late 1990s up until 2022. AFFF containing PFAS was phased out from approximately 2010. AFFF was historically sprayed onto a large mock up (LMU) airplane on a concrete pad and tested on the ground around the pad during firefighting training exercises. Drainage from the training pad collected in

Source area	Extent of PFAS contamination
	underground storage tanks or discharged directly to ground adjacent. The LMU was removed from the area in 2023. Concentrations of PFAS in soils in the source area range up to 10 mg/kg, with an estimated mass of 10.4 kg. Concentrations of PFAS in groundwater range from 7 to 15 µg/L. Drainage infrastructure at the CFTA comprises two underground storage tanks (USTs) that formerly contained fire training fluids. Sediment within these tanks reported concentrations of PFAS between 1.2 and 39 mg/kg.
Former Fire Training Area 2 (FFTA2) (CSR_NT_000091)	This source area (approximately 7,000 m^2) was used for fire training where props and off-specification fuels were burned and extinguished using AFFF containing PFAS. This area operated from the 1970s up until the 1990s. FFTA2 is located within DIA-occupied Commonwealth land, however Defence have committed to assessment and management of PFAS impacts in this source area. Concentrations of PFAS in soils range up to 30.6 mg/kg, with an estimated mass of 19.7 kg[1]. Concentrations of PFAS in groundwater range from 0.07 to 0.08 µg/L.

Notes:
1 – The estimates of PFAS mass in several source areas is based on limited data points and there is some uncertainty in the estimates of mass in these areas. Additional investigations are underway to address and reduce the uncertainty in the estimates.

Table 3-2. Secondary source area of PFAS

Secondary source area	Extent of PFAS contamination
Open drains on-base, Rapid Creek and Ludmilla Creek	The sediments within on-base drains and creeks are secondary sources of PFAS. These drains and creeks are the main surface water pathways where PFAS-impacted surface water leaves the base. Most on-base drains are ephemeral and only flow following heavy rainfall, noting that as groundwater levels rise during the wet season, groundwater may intersect and discharge into the drains towards the end of the wet season. The sediments within the on-base drainage network are a potential secondary source of PFAS impacts. However, annual cleaning of the drains is undertaken, and the sediments removed from the drainage lines (and disposed off-base) to the extent practicable each year. Sediment sampling from on-base drains reported low concentrations of PFAS ranging from <0.005 mg/kg to 0.28 mg/kg adjacent to the CFTA. Rapid Creek and Ludmilla Creek are the main surface water receptors that receive PFAS impacts from groundwater and surface water discharge from the base. The flux of PFAS within the creeks' is partially tied to the volume of water that flows down the creeks, with between 10 to 27 kg of PFAS discharging to Rapid Creek (10-14 kg in a 'dry' wet season, and up to 27 kg in a 'wet' wet season), and between 6 to 7 kg of PFAS discharging to Ludmilla Creek each year. Sediments within the creeks represent a secondary source of PFAS impact. Concentrations of PFAS in sediments in the creeks and tributaries range from <0.005 to 0.39 mg/kg in Rapid Creek, and <0.005 to 0.12 mg/kg in Ludmilla Creek, with most samples reporting concentrations below the laboratory reporting limits.

3.2 Transport pathways

PFAS can travel from a source to human or environmental receptors via transport pathways, such as surface water, groundwater and stormwater within underground drains. Transport pathways identified at and surrounding the base are summarised in Table 3-3.

Table 3-3. PFAS transport pathways

Source area	Transport mechanisms
FFTA1	PFAS migrates in shallow perched groundwater during the wet season, and deeper aquifer throughout the year to the north and discharges to either shallow surface drainage channels approximately 250 m north of the source area or into Rapid Creek approximately 750 m to the north. The flux of PFAS in groundwater prior to remediation was calculated to be approximately 800 grams per year. The flux following remediation is expected to drop by 10% per year. PFAS migrates in surface water from the source area, but the flux in surface water from the source area is minimal and calculated to be less than 20 g per year.
FFF5	PFAS migrates to the north in this area, with a flux of approximately 5 grams per year. PFAS in this groundwater likely discharges to Rapid Creek approximately 900 m to the north.
FFF4	PFAS leaches from soils in this area and migrates in the groundwater to the north and south with approximately 450 g per year leaving the source area. The majority of this is inferred to flow to the north, eventually discharging to Rapid Creek, approximately 1,300 m to the north, except in the late wet season where groundwater flow directions reverse and PFAS migrates to the south across the base boundary and into the suburb of Winnellie. Limited PFAS migrates from the source area in surface water.
FFF6	PFAS leaches from soils in this area and migrates in groundwater to the north and south with approximately 180 g per year leaving the source area. The majority of this is inferred to flow to the north, eventually discharging to Rapid Creek, approximately 1,500 m to the north, except in the late wet season where groundwater flow directions reverse and PFAS migrates to the south across the base boundary and into the suburb of Winnellie. Limited PFAS migrates from the source area in surface water.
Former ARFF Station	PFAS leaches from the impacted soils in this area and migrates towards Rapid Creek, approximately 1,350 m to the north. The PFAS migrates preferentially within higher permeability soils. During the late wet season, groundwater flow direction can reverse, with some PFAS migrating south across the base boundary into the suburb of Winnellie. Limited PFAS migrates from the source area in surface water.
Hangar 31 and FFF1	PFAS migrates to the south-west at approximately 50 g per year in deeper groundwater, contributing to the downgradient PFAS plume from the former RAAF FS prior to discharging across the western boundary. Leaching from the limited residual PFAS in soil is expected to occur but is not considered to have a material impact on PFAS flux migrating from this source area. Limited PFAS migrates from the source area in surface water.
Former RAAF FS	PFAS leaches from soil in this area into groundwater and combines with the PFAS plume from the Hangar 31//FFF1 source areas. The groundwater plume migrates west and south-west prior to discharging across the base western boundary and into the suburb of Ludmilla and Bagot. A large below-ground stormwater pipe at the source area intercepts groundwater for part or all of the year and transports PFAS impacted water directly to Ludmilla Creek, approximately 900 m west of the area. The flux in groundwater across the western base boundary is approximately 50 g per year. The flux in water along the below-ground stormwater drain is between 6 to 7 kg[1] per year. The groundwater PFAS plume in the vicinity and down-gradient of the source area has changed slightly in the most recent ongoing monitoring report (OMR – Tetra Tech Coffey, 2024c), with concentrations of PFAS in groundwater on the western boundary of the site increasing at two monitoring wells. The increases in PFAS concentrations in groundwater on the western boundary may be a transient effect because of isolated temporal influences (i.e. increased rainfall infiltration, disturbance of PFAS impacted soils etc), or an indication that the plume is expanding in this area. Groundwater monitoring will continue in this area to confirm the change in concentrations observed in the recent OMP monitoring.
CFTA	PFAS leaches from soil to shallow perched groundwater and deeper groundwater in this area. The flux in the low permeability aquifer beneath the site is approximately 20 g per

Source area	Transport mechanisms
	year, migrating to the north before discharging to Rapid Creek, approximately 950 m to the northeast. The flux in the shallow higher-permeability perched groundwater is approximately 25 g per 90-day wet season, with migration only occurring when the water table rises into this higher-permeability laterite geology. The perched groundwater PFAS impacts migrate to the north-east towards Rapid Creek and are inferred to discharge to the surface and contribute to the surface water flux approximately 450 m to the north-east of the source area. PFAS migrates in surface water from this source area at approximately 45 g per year, predominantly in the wet season. The surface water flows along open earthen drains to the north, with surface water rapidly infiltrating and contributing to the shallow perched groundwater within approximately 200 m from the source area. No surface water drains in this area connect to Rapid Creek or other surface water drains.
FFTA2	PFAS leaches from soils to shallow perched groundwater and deeper lower permeability groundwater in this area. The flux in shallow perched groundwater is approximately 2 to 15 g per 90-day wet season, and approximately 7.5 g per year in the deeper low-permeability siltstone[2]. PFAS migrates in groundwater to the north-east and discharges to Rapid Creek, approximately 900 m down-gradient. Limited surface water is present within the source area, with most surface water infiltrating into the soils and contributing to the shallow groundwater impacts. Therefore, it has not been possible to estimate the flux of PFAS in surface water.

Notes:
1 – There is some uncertainty and variability in the flux in stormwater from this source area due to the variability in where the PFAS impacted groundwater is entering the drain, and dilution effects due to rainfall induced stormwater from non-impacted areas up-stream and down-stream of the source area. An updated base-wide mass flux assessment is underway to provide improve current mass flux estimates.
2 – Due to limited deep and shallow groundwater transects down-gradient of this source area, there are significant uncertainties in the mass-flux estimates from the FFTA2 source area. An updated base-wide mass flux assessment is underway to improve current mass flux estimates, including from FFTA2 source area.

3.3 Receptors and risks

The receptors that may be exposed to PFAS originating from the base and the associated assessment of the potential risks to the receptors are documented in the Human Health Risk Assessment (HHRA – Coffey, 2018b) and the Ecological Risk Assessment (ERA – Coffey, 2018d). Appendix D provides a summary of the detailed list of potential exposures to PFAS at and off the base and associated risk rankings. These were assessed based on individual source areas or areas of environmental concern (as identified within the DSI, the HHRA and ERA).

The findings of the HHRA and ERA identified several human and ecological receptors (as listed in Table 3-5) with an elevated potential to be exposed to PFAS at or originating from the base. “Elevated” is defined as events that would lead to human exposure over the tolerable daily intake (TDI) or ecological exposure over the screening benchmarks or no observed adverse effect level (NOAEL).

Table 3-4. Receptors with potential elevated exposure

Human Health receptors	Ecological receptors
Consumers of eggs from domestic poultry watered with PFAS-impacted bore water in the suburb of Ludmilla.	Aquatic invertebrates, amphibians and fish in impacted waters of Rapid Creek and Ludmilla Creek.
Consumers of aquatic biota from Rapid Creek or the upper reach of Ludmilla Creek.	Plants and animals in direct contact with soils in source areas.
Base construction or maintenance workers in direct contact with heavily impacted groundwater or effluent in source areas.	Birds and mammals that eat fish from Rapid Creek.
	Birds and mammals that eat plants, invertebrates and reptiles from source areas.

Defence's approach to managing potential elevated exposures to off-base receptors is based on reducing PFAS migrating from the base. Over time this will contribute to the long-term reduction of PFAS in the environment off-base. However, this process will take time and therefore other measures are implemented to reduce risks to human health and the environment. The PFAS migrating from the base and individual source areas has been calculated and refined in previous studies including the Supplementary DSI (Coffey, 2018c) and the baseline Mass Flux Study (Tetra Tech Coffey, 2022).

Figures showing the spatial distribution of PFAS in soil (Figure C2), groundwater (Figure C3) and surface water (Figure C4) are provided in Appendix C.

4 RISK MANAGEMENT ACTIONS

This section outlines the actions that Defence is undertaking to manage the risks associated with PFAS that are described in Section 3.

4.1 Background

In developing actions to address potential risks to receptors from PFAS contamination, Defence considers:

- whether an action is proportional to risks
- the sustainability and longevity of an action (environmental, economic and social) in achieving an appropriate balance between benefits and effects
- views of the jurisdictional regulator and other stakeholders
- availability of best-practice management systems, treatments and technologies
- site specific issues (including transformation, cross-contamination, and remobilisation)
- logistical and operational constraints
- effectiveness and validation status of technology
- success measures for the treatment or remediation outcomes
- the need for ongoing operations, management, maintenance or monitoring
- the net environmental benefit.

Defence prioritises source management and pathway management as preferable to receptor management, but these components may also be progressed concurrently.

4.2 Implementation

Defence takes a risk-based approach to implementing actions under this PMAP and considers value for money when assessing the most effective action/s to attain SFARP. Defence engages consultants to implement the PMAP.

Key factors for progressing and prioritising PMAP actions include:

Mitigating PFAS migration and protecting human health	Implementation of practicable solutions to prevent or minimise the migration of PFAS beyond the Defence property boundary, and measures to protect the community from exposure to PFAS.
Elevated risks	The relative level of risk being addressed, including changes in land use.
Outcomes of completed works	Outcomes from further studies, technology trials or validation of remedial works may change the profile or priority of source areas or works.
Linked actions	Whether the implementation of one response action is dependent on the implementation of another response action.
Use of public resources	Application of the Commonwealth Procurement Rules (issued under the *Public Governance, Performance and Accountability Act 2013*) including the Defence Infrastructure Panel – Environment, Heritage and Estate Engineering Services 2020-2025, to achieve value for money in procurement; and to use public money in an efficient, effective, economical and ethical manner. Cost-effectiveness may be facilitated through:

	• grouping the implementation of similar risk management actions within one or more Management Area • aligning Defence infrastructure and maintenance plans with a PFAS response action.
Mandatory approvals	Timeframes for mandatory approvals and notification processes.
New legislation or policy	Development of relevant legislation, policy, guidelines and whole-of-government positioning.
Science and technology	The availability of new relevant science and technology.
Stakeholder input	Information from stakeholders that may impact a risk profile.

4.3 Completed and ongoing risk management actions

A screening assessment of options to manage the risks presented in Section 3 was undertaken as part of the 2019 PMAP. Based on this assessment, the strategy adopted was a combination of immediate measures to manage potential risks to receptors, and further works to investigate and characterise the nature, extent and flux of PFAS from source areas, to determine feasible remedial measures.

The current status of the actions in the 2019 PMAP are detailed in Table 4-1 below.

Table 4-1. Status of 2019 PMAP recommended actions

Action	Description	Status	Reason / timeframe
Support EPA and Department of Health advisories.	The Northern Territory (NT) Health issued health advisories to limit the consumption of aquatic biota collected from Rapid Creek and to limit recreational swimming in Rapid and Ludmilla Creeks as a result of elevated risks from potential exposure to PFAS.	Current	The concentrations of PFAS in aquatic biota in Rapid Creek, and in surface water in both Rapid Creek and Ludmilla Creek are similar to those measured during the preparation of the HHRA and ERA for the base. A review of the recent concentration data and assumptions from the HHRA and ERA indicates that the potential risks to receptors from PFAS in these surface water bodies has not changed, and therefore the continued support of health advisories should continue.
Controls on soil movement from source areas and off-base transport (applies to all areas of the base).	Soils containing PFAS from source areas may be inadvertently moved, spreading PFAS, and resulting in increased flux from the base.	Current	PFAS containing soils (including those treated at FFTA1) are present at the base and may be moved elsewhere on the base during infrastructure upgrades or maintenance. Until PFAS source areas have been remediated and/or consolidated into treated PFAS areas, this control should remain in place.
Maintain existing stockpile containment and control vegetation. Identify long-term management.	The Wrapped Stockpile Area covers were susceptible to degradation or vegetation encroachment, potentially leading to loss of containment.	Complete	The Wrapped Stockpile Area has been remediated with PFAS impacted soils removed, treated, and consolidated into the FFTA1 source area beneath a cap. The actions have removed the PFAS impacted soils from this area, thereby reducing the movement of PFAS from this source area to the environment.
Access restrictions and personal protective equipment (PPE) controls in the CFTA.	Concentrations of PFAS in sediments within the drainage infrastructure represented a potential risk to maintenance workers.	Current	The PFAS in the sediments within the CFTA drainage infrastructure are still present. These sediments will be removed and treated during upcoming remediation works, at which point this action can be considered complete.
Reduce leaching from CFTA infrastructure	PFAS contained within the CFTA training pad leaches under rainfall conditions, contributing to the flux of PFAS migrating from this area in surface water and groundwater.	Current	The fire-training airplane mock-up has been decommissioned and removed from the CFTA. The concrete pavement has been covered with a high-density polyethylene (HDPE) cover during the wet season for the last two years. The concrete will be removed and treated during upcoming remediation works within the next 18 months at which point this action can be considered complete.
Controls on ground disturbance activities and	PFAS within soils and shallow groundwater in source areas potentially represents a risk to construction or maintenance workers who may be	Current	As PFAS is still present in soils and shallow groundwater at concentrations which potentially present an elevated risk to

Action	Description	Status	Reason / timeframe
management of excavation works via access controls.	exposed to the impacted soils or groundwater. All PFAS source areas are listed on the base's Contaminated Sites Register, and any ground disturbances on the base must consider any PFAS source areas to control potential exposures.		construction or maintenance workers, this action is required to control potential exposure to PFAS impacts.
Investigate source management of soils in FFTA1, CFTA and FFTA2 via capping, immobilisation or source removal (soil) managed by thermal or on-base containment cell.	The FFTA1, FFTA2 and CFTA source areas all presented a potential high risk to receptors in Rapid Creek and terrestrial ecological receptors. Consequently, it was recommended that remedial actions were investigated and developed to reduce the flux of PFAS from these areas, as well as the potential exposure to terrestrial ecological receptors.	FFTA1 – Complete FFTA2, CFTA - Current	Remediation of PFAS impacts at FFTA1 has been undertaken with PFAS soils excavated, removed from the base for thermal destruction, or treated to immobilise PFAS and the treated soils reinstated beneath a clay cap, and this action is considered complete. The completed action has reduced the leaching of PFAS from the treated soils and reduced infiltration, thereby reducing the movement of PFAS from this source area into the environment. The CFTA source area has been investigated and is planned for remediation to reduce the flux of PFAS migrating from the source area and reduce exposure to terrestrial ecological receptors. PFAS impacted soils and concrete will be treated to reduce leachability and reinstated at the source area. The FFTA2 source area is currently under investigation to assess the feasibility of undertaking remediation of PFAS in soils to reduce the flux of PFAS and exposure to terrestrial ecological receptors.
Review drainage network and investigate options to divert and treat captured water in stormwater system.	PFAS migration in the drainage network, including open earthen drains and below-ground drainage systems is a secondary pathway for PFAS migration to Rapid and Ludmilla Creeks. Investigating the drainage network, including the cumulative volume of water and relative concentrations would inform the feasibility of implementing treatment of PFAS impacted surface water.	Current	The drainage network was investigated as a part of the Mass Flux Study (Tetra Tech Coffey, 2022) and identified that the drainage pipelines that lead from the former RAAF FS to Ludmilla Creek intercept PFAS impacted groundwater, resulting in direct discharge to Ludmilla Creek. Options to intercept the PFAS infiltrating into the pipelines were investigated via a relining approach but were considered not feasible given the potential to result in increased PFAS migration in groundwater or via other surface water pathways. This activity is still underway with other potential feasible technologies being investigated including via passive reactive barriers.
Investigate groundwater treatment or immobilisation of Former ARFF Station.	The concentrations and mass of PFAS in soils and groundwater at the ARFF represent a significant ongoing source of PFAS flux to Rapid Creek and	Current	Additional investigations at the Former ARFF Station have led to the development of a remedial strategy for removing PFAS from soils at the source area via in-situ soil washing. A pilot

Action	Description	Status	Reason / timeframe
	investigation of potential management options to reduce flux or remove PFAS to reduce the risks to Rapid Creek receptors was warranted.		study has been developed and is proposed to be implemented at the site to test the efficacy of the proposed method. Depending on the effectiveness of the proposed remedial method, a semi-permanent system may be installed and operated over the wet season to reduce the mass of PFAS in the source area, with annual reviews of the efficacy of the system.
Investigate capping, immobilisation or source removal (soil) managed by thermal or on-base containment cell at FFF4, FFF6, FFF1 and Hangar 31 Potential for co-management of stockpiled soils from former FFF1, FFTA2 and Wrapped Stockpile Area.	The FFF4, FFF6, FFF1 and Hangar 31 source areas all presented a potential medium risk to receptors in Rapid Creek and Ludmilla Creeks, and terrestrial ecological receptors. Consequently, it was recommended that remedial actions were investigated and developed to reduce the flux of PFAS from these areas, as well as the potential exposure to terrestrial ecological receptors.	Current	The Wrapped Stockpile Area was remediated in 2023 with stockpiles treated and instated beneath the cap at FFTA1 during the remediation of this source area. A remedial action plan has been developed for the FFF4 and FFF6 source areas to excavate and treat PFAS impacted soils to immobilise PFAS and reinstated the treated soils at the CFTA. Soil removal works associated with base infrastructure projects has resulted in large volumes of PFAS impacted soils at FFF1 and Hangar 31 being removed from the source areas and reinstated within the base's beneficial soil reuse area. Additional investigations assessing the residual soil impacts at FFF1, and Hangar 31 are currently underway and will inform the feasibility or requirement to undertaken additional actions to manage potential impacts to receptors.
Integrate PFAS control evaluation into siting and design review for future capital works on base.	As there are many PFAS source areas on the base, there is the potential for overlap of construction activities to either disturb PFAS impacted soils, or beneficially remove or reduce the flux from PFAS impacted soils as a part of capital works. This action was developed to ensure that future works considered the potential to co-manage PFAS impacts where capital works projects overlapped	Current	Several PFAS source areas with impacted soils remain on the base and whilst they remain, consideration of potential project overlap should be undertaken to ensure that spreading of PFAS impacts does not occur, and that any PFAS impacted soils can be beneficially managed as a part of any project. Until all PFAS impacted soils are removed and/or consolidated, this measure should remain in place.

4.4 Additional risk management actions

Additional management actions have been identified since publication of the 2019 PMAP. A description and the status of these actions are set out in Table 4-2 below.

Table 4-2. Status of additional risk management actions

Action	Description	Status
Investigate groundwater treatment at FFF4 and FFF6	PFAS in groundwater at FFF4 and FFF6 results in approximately 600 g of PFAS per year migrating from the source area in groundwater towards both Rapid Creek and off the base to the south. Given the presence of a high-permeability aquifer beneath these source areas, and the potential feasibility of implementing a groundwater treatment system to reduce the mass of PFAS in groundwater, further investigation of the potential effectiveness of such a system is warranted. The investigation will inform whether additional actions to reduce PFAS flux in the source areas following the soil remediation are feasible, or whether remediation has been achieved so far as reasonably practicable.	Current
Investigate remediation options at former RAAF FS	PFAS in groundwater at and downgradient of the former RAAF FS has been changing, with PFAS concentrations on the western boundary of the base increasing in recent monitoring rounds. The concentrations of PFAS in groundwater at this source area have stayed consistently high, and potentially show an increasing trend in the dry season. Further investigation of the mass of PFAS in soils and the flux of PFAS in groundwater from this source area is required to inform how PFAS infiltrating into the stormwater drains in this area can be managed.	Current
Implement remediation once remediation actions plans are developed	Several management actions from the 2019 PMAP were focused on investigating how to manage PFAS in source areas, as at the time, it was uncertain which remedial methods could be practicably applied to reduce migration of PFAS. Following the identification of successful remedial technologies, and the development of remediation action plans for several source areas at the base remedial actions will be implemented.	FFTA1, Wrapped Stockpile Area – Complete FFF4, FFF6, CFTA – Current

4.5 Completed remediation

Remediation of two source areas, i.e. the Wrapped Stockpile Area and FFTA1, has been completed at the base (Tetra Tech Coffey, 2024b).

The Wrapped Stockpile Area is considered to have been remediated so far as reasonably practicable (SFARP), with the residual PFAS impacts in soils considered to be negligible, and unlikely to represent a potential risk to human health or ecological receptors. The removal of the majority of PFAS impacts in soils in this source area reduces the potential for PFAS to leach into surface water and groundwater. Over time this reduces the potential overall mass of PFAS migrating from the base, thereby reducing the potential risks to human health or ecological receptors.

The remediation works at FFTA1 have removed or stabilised over 70% of the mass of PFAS in the source area. The treatment of the PFAS impacted soils at the source area has reduced the potential leachability of the PFAS by over 95% and will reduce the mass of PFAS leaching and migrating from the source area in surface water and groundwater.

Ongoing monitoring of PFAS in groundwater and surface water will be completed to confirm the effectiveness of this action in reducing movement of PFAS and the overall reduction in PFAS migrating from the base, and whether the remediation objectives have been met.

4.6 Ongoing monitoring and trigger levels

Defence continues to monitor PFAS concentrations in the environment at the base through an ongoing monitoring program. This allows for the timely identification and management of emerging risks and informs Defence's approach to the management of PFAS. Emerging risks relates to changing PFAS concentrations in a particular media (i.e. surface water, groundwater or biota) that are currently below the screening criteria, but if increasing trends continue, then the potential for receptors to be exposed to PFAS above the criteria may occur. Monitoring requirements are outlined in an Ongoing Monitoring Plan (OMP). The OMP is reviewed annually and, if required, amended to ensure it continues to provide the data needed to monitor important changes in PFAS concentrations and distribution.

Results from ongoing monitoring are shared with the NT EPA and are provided in an Ongoing Monitoring Report, available on the Defence website. The Ongoing Monitoring Report provides the latest available PFAS data, and an analysis of what important changes in concentrations may mean to the profile of PFAS contamination set out in the CSM, or potential changes to risks to humans or the environment.

Based on the data collected to date, and the 2024 Ongoing Monitoring Report, changes to the CSM for RAAF Base Darwin were identified, as outlined in Section 3.

The OMP outlines triggers and actions that Defence will undertake if certain results or trends are reported from the ongoing monitoring. This includes actions to confirm the accuracy of results, notification to the NT EPA and other agencies upon new PFAS detections or increasing trends and implementing additional investigations and risk management actions if the monitoring data indicates changes to the current risk profile.

5 NEXT STEPS

Defence will carry out the risk management actions set out in this PMAP and continue to reassess these actions based on a range of factors, such as the outcomes of remediation, monitoring results, changes to government policy settings, site conditions and scientific methodologies and technologies.

Defence will review and, if required, revise the PMAP at regular intervals to ensure the PMAP remains current, relevant and prioritises the right actions to protect human health and the environment. Defence will continue to engage with the community, the Council, NT EPA, NT Department of Health, DIA, and other stakeholders to ensure information is available in an easily accessible form.

It is not possible to remove all PFAS from the environment. Remediation at the base will be undertaken so far as reasonably practicable, and elevated risks that may remain will be identified through monitoring, and appropriately managed.

In determining what is reasonably practicable, a range of aspects will be considered, including the:

- level of risk from PFAS to human and ecological receptors
- environmental site setting
- nature and extent of PFAS contamination
- availability and applicability of proven technologies suitable for the characteristics of the site
- logistical and operational constraints of the site, and
- financial and sustainability aspects of each technology.

At completion of remediation, an independent professional, accredited under at least one of the New South Wales, Victorian, South Australian, Western Australian and Queensland Site Auditor Schemes will be engaged by Defence to assess whether remediation has been conducted so far as reasonably practicable. The PMAP will then be updated to reflect a transition to ongoing monitoring, and long-term management of remaining risks.

APPENDIX A REFERENCES

Key documents

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Coffey (2019b) RAAF Base Darwin – Annual PFAS Monitoring Report, sampling conducted March 2019. 754-MELEN199421-R15, dated 16 July 2019, Coffey Environments Australia Pty Ltd Melbourne

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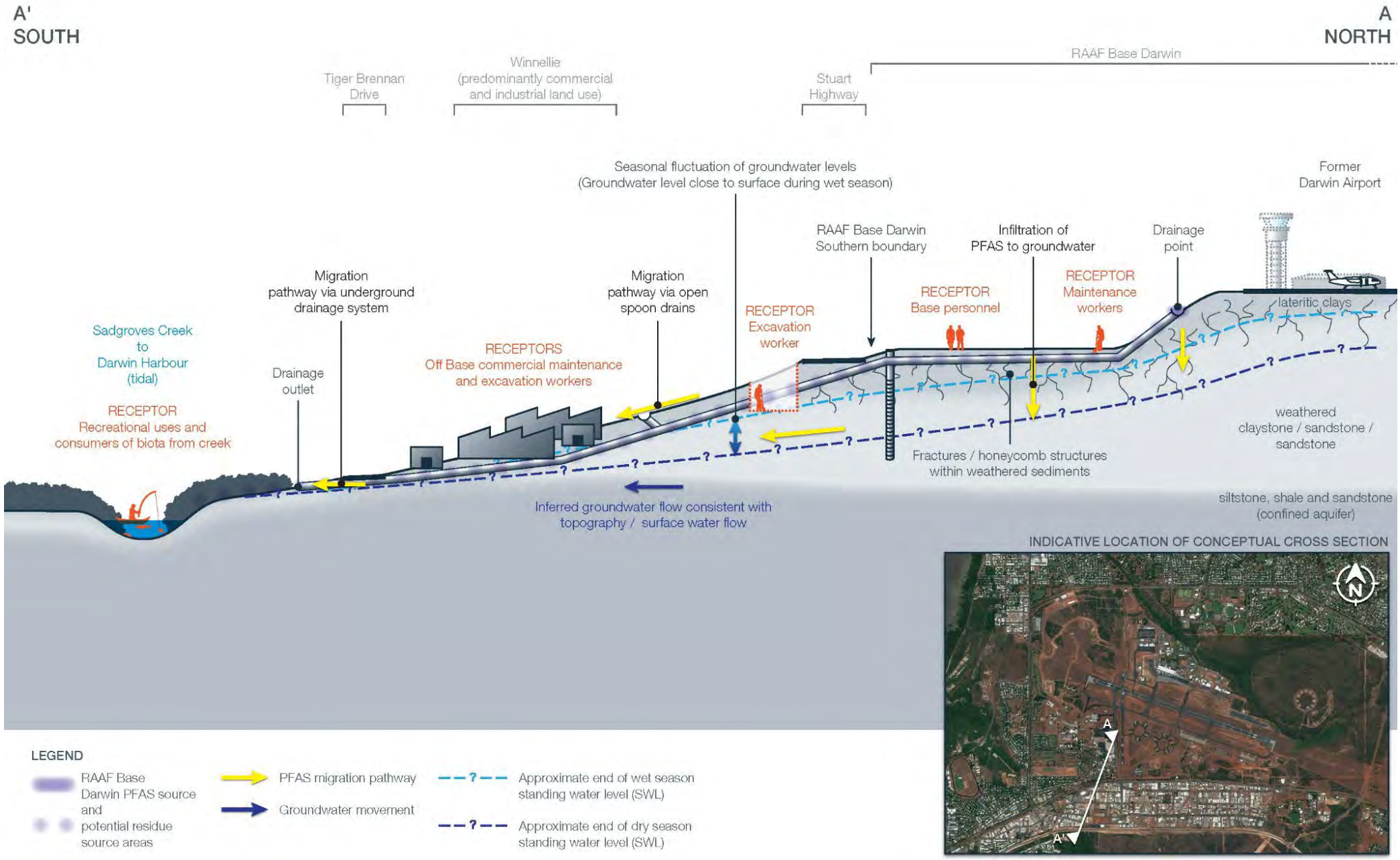
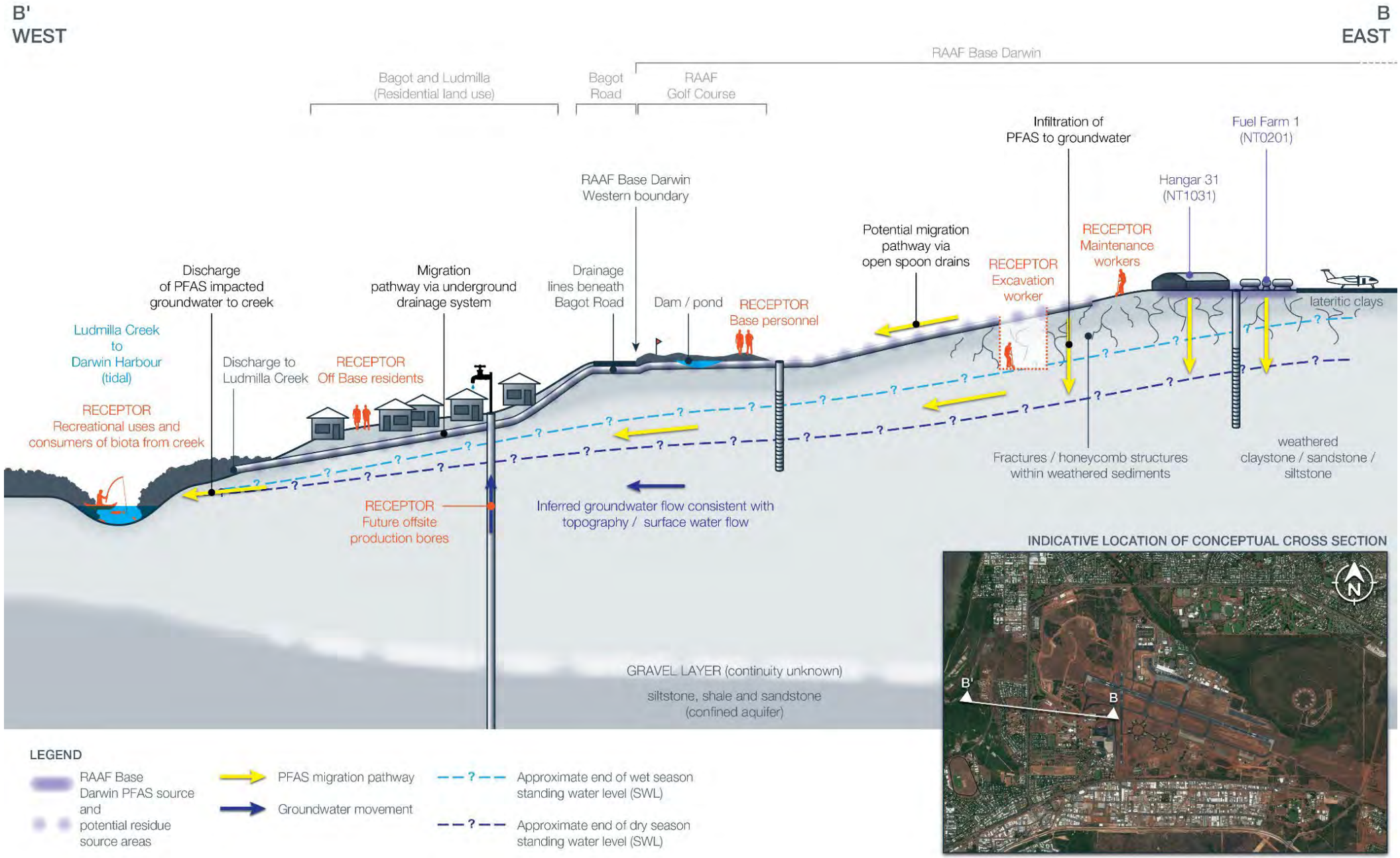
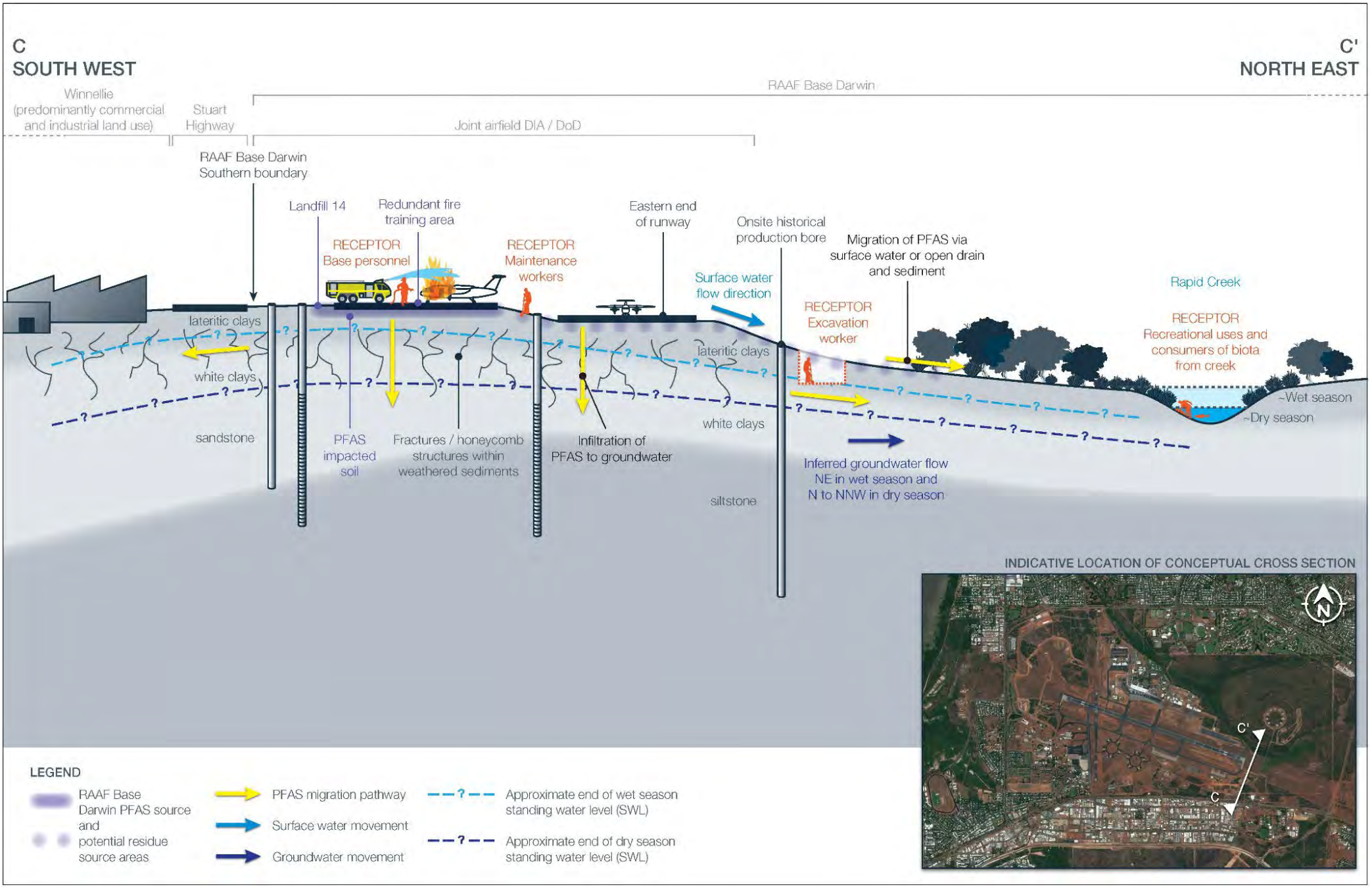
Tetra Tech Coffey. (2024a). Department of Defence, RAAF Base Darwin – PFAS Investigation, CFTA and Former ARFF Further Investigations 2022, 754-MELEN199421-R34

APPENDIX B CONCEPTUAL SITE MODEL

This Appendix provides visualisations of the source – pathway – receptor relationships in the form of a Conceptual Site Model.


A'
SOUTH
A
NORTH
RAAF Base Darwin
Tiger Brennan Drive
Winnellie (predominantly commercial and industrial land use)
Stuart Highway
Seasonal fluctuation of groundwater levels (Groundwater level close to surface during wet season)
Former Darwin Airport
RAAF Base Darwin Southern boundary
Infiltration of PFAS to groundwater
Drainage point
RECEPTOR Maintenance workers
RECEPTOR Base personnel
RECEPTOR Excavation worker
Migration pathway via underground drainage system
Migration pathway via open spoon drains
lateritic clays
Sadgroves Creek to Darwin Harbour (tidal)
RECEPTORS Off Base commercial maintenance and excavation workers
Drainage outlet
RECEPTOR Recreational uses and consumers of biota from creek
weathered claystone / sandstone / sandstone
Fractures / honeycomb structures within weathered sediments
Inferred groundwater flow consistent with topography / surface water flow
siltstone, shale and sandstone (confined aquifer)
INDICATIVE LOCATION OF CONCEPTUAL CROSS SECTION
A
A'
N
LEGEND
RAAF Base Darwin PFAS source and potential residue source areas
PFAS migration pathway
Groundwater movement
Approximate end of wet season standing water level (SWL)
Approximate end of dry season standing water level (SWL)


B'
WEST
B
EAST
RAAF Base Darwin
Bagot and Ludmilla
(Residential land use)
Bagot
Road
RAAF
Golf Course
Infiltration of
PFAS to groundwater
Fuel Farm 1
(NT0201)
RAAF Base Darwin
Western boundary
Hangar 31
(NT1031)
Potential migration
pathway via
open spoon drains
RECEPTOR
Maintenance
workers
RECEPTOR
Excavation
worker
Discharge
of PFAS impacted
groundwater to creek
Migration
pathway via underground
drainage system
Drainage
lines beneath
Bagot Road
Dam / pond
RECEPTOR
Base personnel
lateritic clays
Ludmilla Creek
to
Darwin Harbour
(tidal)
Discharge to
Ludmilla Creek
RECEPTOR
Off Base residents
RECEPTOR
Recreational uses and
consumers of biota from creek
Fractures / honeycomb structures
within weathered sediments
weathered
claystone / sandstone /
siltstone
RECEPTOR
Future offsite
production bores
Inferred groundwater flow consistent with
topography / surface water flow
GRAVEL LAYER (continuity unknown)
siltstone, shale and sandstone
(confined aquifer)
INDICATIVE LOCATION OF CONCEPTUAL CROSS SECTION
B'
B
N
LEGEND
RAAF Base
Darwin PFAS source
and
potential residue
source areas
PFAS migration pathway
Groundwater movement
Approximate end of wet season
standing water level (SWL)
Approximate end of dry season
standing water level (SWL)


C
SOUTH WEST
C'
NORTH EAST
Winnellie
(predominantly commercial and industrial land use)
Stuart Highway
RAAF Base Darwin
Joint airfield DIA / DoD
RAAF Base Darwin
Southern boundary
Landfill 14
Redundant fire training area
Eastern end of runway
Onsite historical production bore
Migration of PFAS via surface water or open drain and sediment
RECEPTOR
Base personnel
RECEPTOR
Maintenance workers
Surface water flow direction
RECEPTOR
Excavation worker
Rapid Creek
RECEPTOR
Recreational uses and consumers of biota from creek
lateritic clays
white clays
sandstone
PFAS impacted soil
Fractures / honeycomb structures within weathered sediments
Infiltration of PFAS to groundwater
lateritic clays
white clays
siltstone
Inferred groundwater flow
NE in wet season and
N to NNW in dry season
~Wet season
~Dry season
INDICATIVE LOCATION OF CONCEPTUAL CROSS SECTION
N
C'
C
LEGEND
RAAF Base Darwin PFAS source and potential residue source areas
PFAS migration pathway
Surface water movement
Groundwater movement
Approximate end of wet season standing water level (SWL)
Approximate end of dry season standing water level (SWL)

APPENDIX C FIGURES

List of Figures

LEGEND

- Creek
- PFAS source area
- Base boundary
- Management area

ID	Source Area
1	Former Fire Training Area 1 (FFTA1). *Also previously called Former Fire Training Ground 1*
2	Former Fuel Farm 5 (FFF5)
3	Former Fuel Farm 4 (FFF4)
4	Former Fuel Farm 6 (FFF6)
5	Wrapped Stockpiles Area *Also previously called the 'AFFF Contaminated Soil Stockpiles'*
6	Former Aviation Rescue Fire Fighting (ARFF) Fire Station
7	Hangar 31
8	Former Fuel Farm 1 (FFF1)
9	Former RAAF Fire Station (Former RAAF-FS)
10	Former Fire Training Area 2 (FFTA2)
11	Current (Hot) Fire Training Area (CFTA)

SOURCE
Inferred PFAS source areas from site history information.
RAAF Base Darwin site boundary, roads, tracks, and creeks from DoD.
Imagery from Nearmap (06-06-2021).

0 500 1,000 m

SCALE **1:40,000**
PAGE SIZE: **A3**
PROJECTION: **GDA 1994 MGA Zone 52**

DEPARTMENT OF DEFENCE

RAAF BASE DARWIN - PMAP

FIGURE C1

Site location, Management Area and Source Areas

TETRA TECH COFFEY

DATE: **04.09.24** PROJECT: **754-MELEN338204** FILE: **338204_R10_PMAP_F00C1_GIS**

701,500 | 702,000 | 702,500 | 703,000 | 703,500 | 704,000 | 704,500 | 705,000 | 705,500 | 706,000 | 706,500

8,629,000 | 8,628,500 | 8,628,000 | 8,627,500 | 8,627,000 | 8,626,500 | 8,626,000 | 8,625,500 | 8,625,000

Rapid Creek

LEGEND

- Soil sampling locations
- Creek

Sum of PFHxS and PFOS (mg/kg)

- >20
- >10-20
- >1-10
- >0.01-1.00
- LOR to 0.01
- Below LOR
- Management area
- PFAS source area
- Base boundary

SOURCE
Inferred PFAS source areas from site history information.
Sampling locations from Tetra Tech Coffey
RAAF Base Darwin site boundary, roads, tracks, and creeks from DoD.
Imagery from Nearmap (06-06-2021).

0 250 500 m

N

SCALE **1:17,500**
PAGE SIZE: **A3**
PROJECTION: **GDA 1994 MGA Zone 52**

DEPARTMENT OF DEFENCE

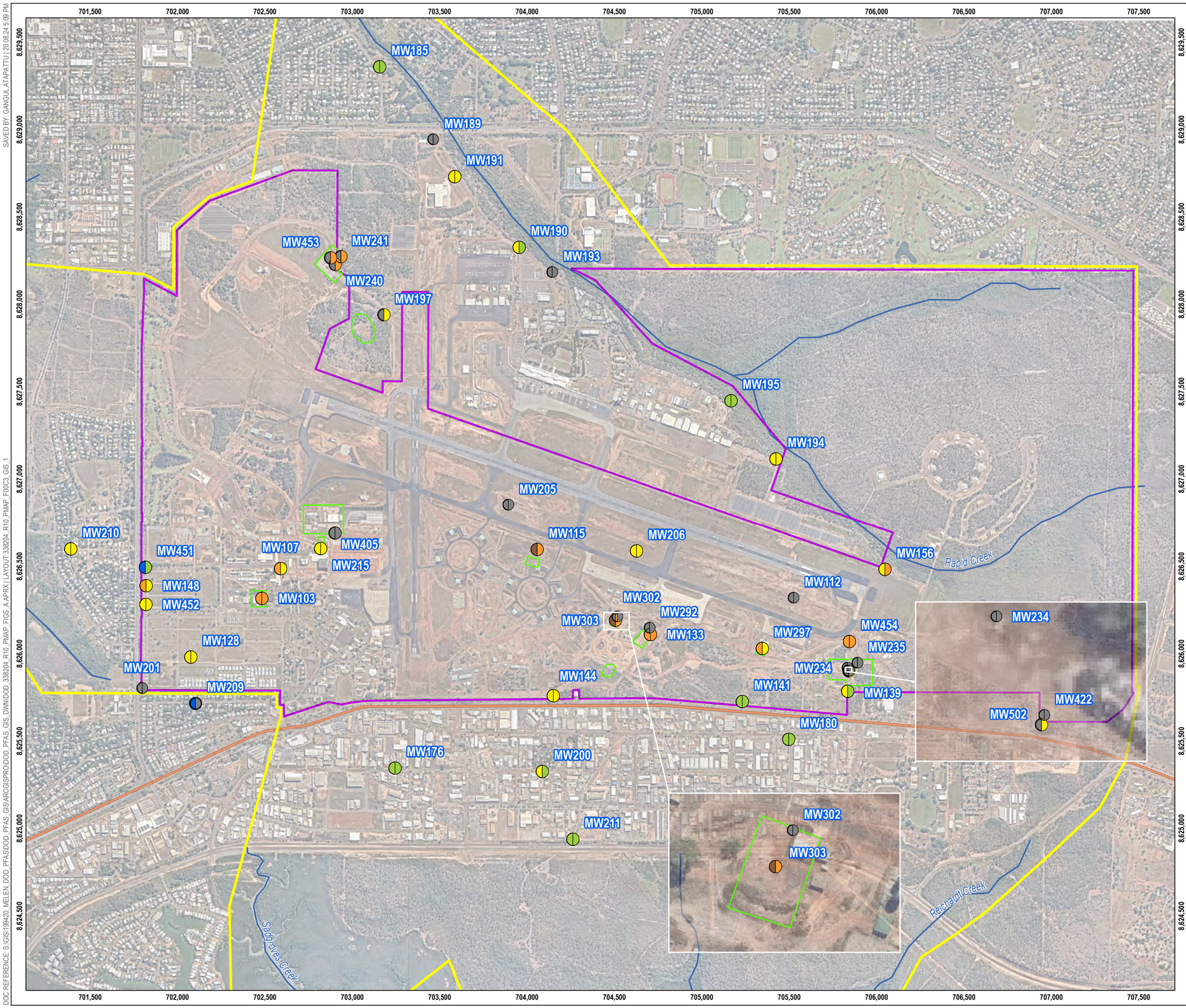
RAAF BASE DARWIN - PMAP

FIGURE C2

Spatial distribution of Sum of PFOS + PFHxS in soils

TETRA TECH COFFEY

DATE: **04.09.24** PROJECT: **754-MELEN338204** FILE: **338204_R10_PMAP_F00C2_GIS**



LEGEND

Sum of PFOS and PFHxS

- Below LOR
- LOR to 0.07ug/L
- 0.07 to 0.7 ug/L
- 0.7 to 7 ug/L
- 7 to 70 ug/L
- >= 70 ug/L
- Not sampled
- Sampled in Dry season (2023)
- Sampled in Wet season (2024)
- Stuart highway
- Creek
- PFAS source area
- Base boundary
- Management area

SOURCE
Inferred PFAS source areas from site history information.
Sampling locations from Tetra Tech Coffey
RAAF Base Darwin site boundary, roads, tracks, and creeks from DoD.
Imagery from Nearmap (06-06-2021).

0 250 500 m

SCALE **1:21,000**
PAGE SIZE: **A3**
PROJECTION: **GDA 1994 MGA Zone 52**

DEPARTMENT OF DEFENCE

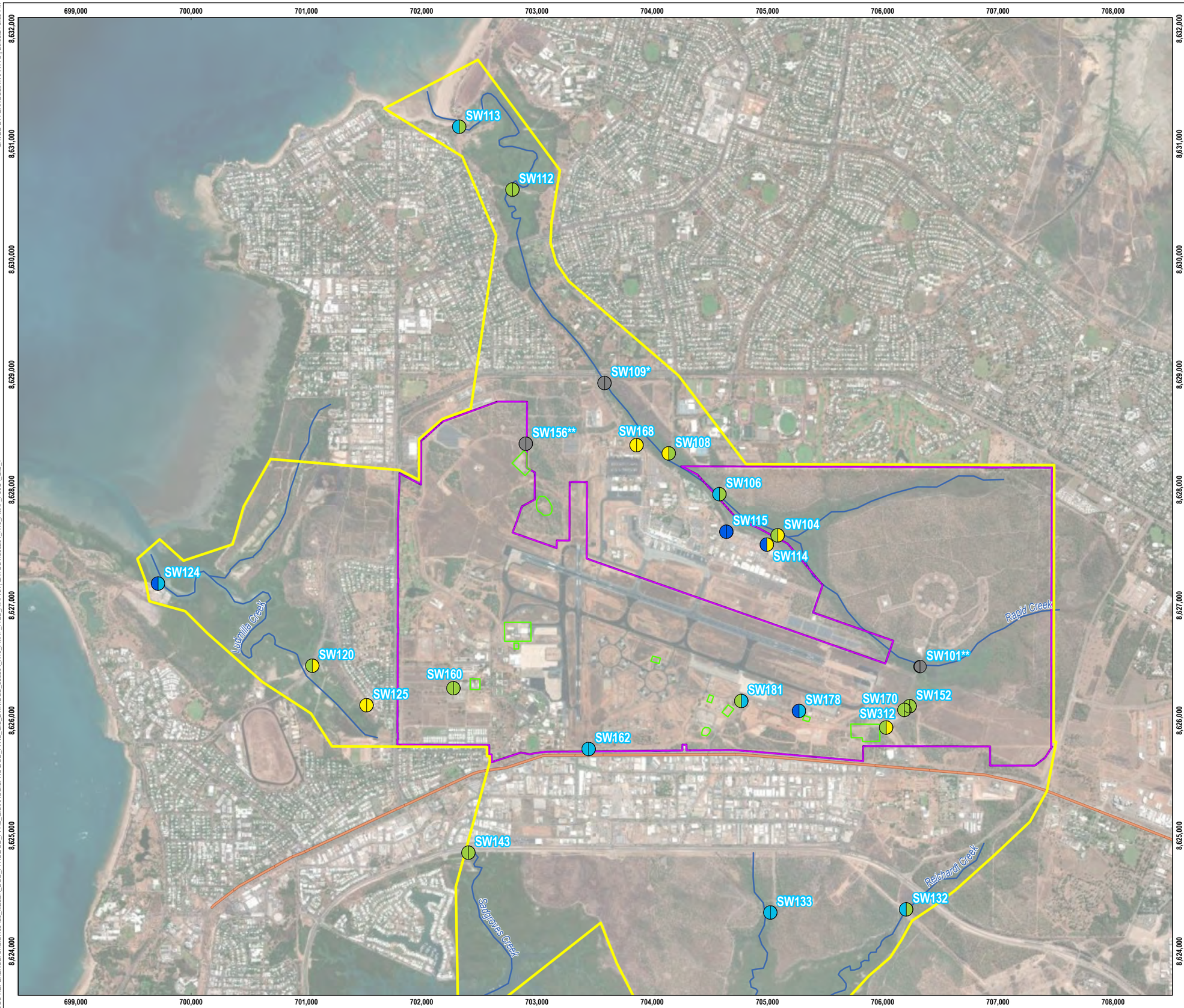
RAAF BASE DARWIN - PMAP

FIGURE C3

Spatial distribution of Sum of PFOS+PFHxS in groundwater, June 2023 to April 2024

TETRA TECH COFFEY

DATE: **04.09.24** PROJECT: **754-MELEN338204** FILE: **338204_R10_PMAP_F00C3_GIS**



LEGEND

Sum of PFOS and PFHxS

- Below LOR
- LOR to 0.07ug/L
- 0.07 to 0.7 ug/L
- 0.7 to 7 ug/L
- 7 to 70 ug/L
- >= 70 ug/L
- Not sampled
- Sampled in Start of wet season (2023)
- Sampled in End of wet season (2024)
- Creek
- PFAS source area
- Base Boundary
- Management area

SOURCE
Inferred PFAS source areas from site history information.
Sampling locations from Tetra Tech Coffey
RAAF Base Darwin site boundary, roads, tracks, and creeks from DoD.
Imagery from Nearmap (06-06-2021).

0 500 1,000 m

SCALE **1:32,000**
PAGE SIZE: **A3**
PROJECTION: **GDA 1994 MGA Zone 52**

DEPARTMENT OF DEFENCE

RAAF BASE DARWIN - PMAP

FIGURE C4

Spatial distribution of Sum of PFOS+PFHxS in surface water, June 2023 to April 2024

TETRA TECH COFFEY

DATE: **04.09.24** PROJECT: **754-MELEN338204** FILE: **338204_R10_PMAP_F00C4_GIS**

SAVED BY: GANGULATAPATTU | 20.08.24 5:09 PM
DOC REFERENCE: S:\GIS\199420_MELEN_DOD_PFAS\DOD_PFAS_GIS\ARCGISPRO\DOD_PFAS_GIS_DWM\DOD_338204_R10_PMAP_FIGS_A.APRX | LAYOUT:338204_R10_PMAP_F00C4_GIS_1

APPENDIX D RISK ASSESSMENT SUMMARY

The likelihood and consequence descriptors have been based on the Department of Defence Contamination Risk Assessment Tool guidance definitions, with human health and ecological risks assessed against "Environment – Stage 3 Risk Assessment" criteria and are detailed in Table D-1 below. The consequence descriptors were selected based on the risk assessment methodology applied during the risk assessments (Coffey 2018b, 2018d). To estimate the additive effect of exposure to multiple PFAS compounds, the hazard quotient (a ratio of the estimated exposure to the tolerable concentration of a particular PFAS compound) can be summed to obtain a Hazard Index for a particular receptor.
Where HI is less than 1, there is unlikely to be any adverse health effects associated with exposure to the chemicals of concern. However, a HI exceeding 1 does not necessarily indicate an actual risk but rather a potential adverse health outcome requiring additional assessment.

Table D-5-1. Descriptors used to classify likelihood and consequence

Descriptor	Description
Likelihood	
Rare	May occur only in exceptional circumstances
Unlikely	May occur in the future
Possible	Might occur within the next 10 years
Likely	Will probably occur within the next year
Current	Either occurring or almost certainly will occur
Consequence	
Severe	Imminent risk of harm to Human Health or Ecological receptors
Major	Hazard index greater than 10
Moderate	Hazard index between 1 and 10
Minor	Hazard index between 0.1 and 1
Insignificant	Hazard index less than 0.1

The risk of a receptor to be exposed to potentially unacceptable concentrations of PFAS was then determined by combining the likelihood and consequence to rank the potential risk as very high, high, medium, low or very low according to the risk evaluation matrix in Table D-2 below.

Table D-5-2. Risk evaluation matrix

		Likelihood				
		Rare	Unlikely	Possible	Likely	Current
Consequence	Insignificant	Very low	Very low	Very low	Low	Medium
	Minor	Very low	Low	Low	Medium	Medium
	Moderate	Low	Low	Medium	High	High
	Major	Low	Medium	High	Very high	Very high
	Severe	Medium	High	Very high	Very high	Very high

To provide an indication of what each consequence category is based on, health and ecological risks are interpreted in isolation and the highest ranked risk is adopted. The elevated risks are described in the table for each source area and if the identified risk is a Human Health (HH) risk or an Ecological Exposure (Eco) risk as denoted by a ✓.

A full list of risks identified in the DSI, HHRA and ERA is provided in Table D-3 below.

Table D-3. Risk assessment summary

Source Area	ID	Identified Exposure Pathway	HH	Eco	Likelihood	Consequence	Exposure Risk
FFTA1	A1	Movement of soil to more sensitive areas may present an elevated exposure potential to receptors	✓	✓	Possible	Moderate	Medium
	A2	Migration of PFAS in groundwater represents a source of impact to Rapid Creek, resulting in human health exposure through consumption of fish	✓		Current	Moderate	High
	A3	Migration of PFAS in groundwater represents a source of impact to Rapid Creek, resulting in ecological exposure to terrestrial and aquatic ecosystems		✓	Current	Moderate	High
	A4	Extended contact with groundwater during construction excavation works may represent significant human exposure	✓		Unlikely	Minor	Low
	A5	Direct contact with soil represents elevated exposure to terrestrial flora and fauna		✓	Current	Moderate	High
FFF5	B1	Movement of soil to more sensitive areas may present an elevated exposure potential to receptors	✓	✓	Possible	Minor	Low
	B2	Migration of PFAS in groundwater represents a source of impact to Rapid Creek, resulting in human health exposure through consumption of fish	✓		Current	Minor	Medium
	B3	Migration of PFAS in groundwater represents a source of impact to Rapid Creek, resulting in ecological exposure to terrestrial and aquatic ecosystems		✓	Current	Minor	Medium
FFF4 & FFF6	C1	Movement of soil to more sensitive areas may present an elevated exposure potential to receptors	✓	✓	Possible	Moderate	Medium
	C2	Extended contact with groundwater during construction excavation works may represent significant human exposure	✓		Unlikely	Minor	Low
	C3	Migration of PFAS in groundwater represents a source of impact to Rapid Creek, resulting in human health exposure through consumption of fish	✓		Current	Moderate	High
	C4	Migration of PFAS in groundwater represents a source of impact to Rapid Creek, resulting in ecological exposure to terrestrial and aquatic ecosystems		✓	Current	Moderate	High
	C5	Direct contact with soil represents elevated exposure to terrestrial flora and fauna		✓	Possible	Minor	Low
Former ARFF Station	D1	Movement of soil to more sensitive areas may present an elevated exposure potential to receptors	✓	✓	Rare	Moderate	Low
	D2	Extended contact with groundwater during construction excavation works may represent significant human exposure	✓		Unlikely	Minor	Low

Source Area	ID	Identified Exposure Pathway	HH	Eco	Likelihood	Consequence	Exposure Risk
	D3	Migration of PFAS in groundwater represents a source of impact to Rapid Creek, resulting in human health exposure through consumption of fish	✓		Current	Moderate	High
	D4	Migration of PFAS in groundwater represents a source of impact to Rapid Creek, resulting in ecological exposure to terrestrial and aquatic ecosystems		✓	Current	Moderate	High
Wrapped Stockpile Area	E1	Movement of soil to more sensitive areas may present an elevated exposure potential to receptors	✓	✓	Possible	Insignificant	Very low
Hangar 31 & FFF1	F1	Movement of soil to more sensitive areas may present an elevated exposure potential to receptors	✓	✓	Possible	Minor	Low
	F2	Migration of PFAS in groundwater water represents a source of impact to Ludmilla Creek, resulting in human health exposure through swimming or consumption of fish	✓		Current	Minor	Medium
	F3	Migration of PFAS in groundwater represents a source of impact to Ludmilla Creek, resulting in ecological exposure to terrestrial and aquatic ecosystems		✓	Current	Moderate	High
	F4	Migration of PFAS in groundwater represents a potential exposure to off-base residents through groundwater use	✓		Unlikely	Moderate	Low
	F5	Direct contact with soil represents elevated exposure to terrestrial flora and fauna		✓	Unlikely	Minor	Low
Former RAAF FS	G1	Movement of soil to more sensitive areas may present an elevated exposure potential to receptors	✓	✓	Possible	Minor	Low
	G2	Groundwater containing PFAS migrating into surface water drains represents a source of impact to Ludmilla Creek, resulting in human health exposure through swimming or consumption of fish	✓		Current	Minor	Medium
	G3	Groundwater containing PFAS migrating into surface water drains represents a source of impact to Ludmilla Creek, resulting in ecological exposure to terrestrial and aquatic ecosystems		✓	Current	Moderate	High
	G4	Migration of PFAS in groundwater water represents a source of impact to Ludmilla Creek, resulting in human health exposure through swimming or consumption of fish	✓		Current	Minor	Medium
	G5	Migration of PFAS in groundwater or surface water represents a source of impact to Ludmilla Creek, resulting in ecological exposure to terrestrial and aquatic ecosystems		✓	Current	Moderate	High
	G6	Migration of PFAS in groundwater represents a potential exposure to off-base residents through groundwater use	✓		Unlikely	Moderate	Low

Source Area	ID	Identified Exposure Pathway	HH	Eco	Likelihood	Consequence	Exposure Risk
	G7	Extended contact with groundwater during construction excavation works may represent significant human exposure	✓		Unlikely	Moderate	Low
	G8	Direct contact with soil represents elevated exposure to terrestrial flora and fauna		✓	Unlikely	Minor	Low
CFTA	H1	Movement of soil to more sensitive areas may present an elevated exposure potential to receptors	✓	✓	Possible	Moderate	Medium
	H2	Surface water run off represents a source of impact to Rapid Creek, resulting in human health exposure through consumption of fish	✓		Current	Minor	Medium
	H3	Surface water run off represents a source of impact to Rapid Creek, resulting in ecological exposure to terrestrial and aquatic ecosystems		✓	Current	Minor	Medium
	H4	Extended contact with groundwater during construction excavation works may represent significant human exposure	✓		Unlikely	Minor	Low
	H5	Migration of PFAS in groundwater represents a source of impact to Rapid Creek, resulting in human health exposure through consumption of fish	✓		Current	Minor	Medium
	H6	Migration of PFAS in groundwater represents a source of impact to Rapid Creek, resulting in ecological exposure to terrestrial and aquatic ecosystems		✓	Current	Minor	Medium
	H7	Regular contact with effluent in tanks may represent significant human exposure	✓		Current	Moderate	High
	H8	Direct contact with soil represents elevated exposure to terrestrial flora and fauna		✓	Current	Moderate	High
FFTA2	I1	Movement of soil to more sensitive areas may present an elevated exposure potential to receptors	✓	✓	Possible	Minor	Low
	I2	Direct contact with soil represents elevated exposure to terrestrial flora and fauna		✓	Unlikely	Minor	Low