Final Site Condition HMAS Cerberus

PFAS Investigation and Management Program

Department of Defence

16 April 2025

→ The Power of Commitment

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<tr><th colspan="2">Project name</th><td colspan="6">Technical Advisor RAAF Base East Sale and HMAS Cerberus</td></tr>
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Executive Summary

The Department of Defence (Defence) is undertaking a national program to investigate, remediate and manage impacts of per- and poly-fluoroalkyl substances (PFAS) on and in the vicinity of its bases around Australia. As part of this program, Defence has engaged Dr. Peter Beck of GHD as the Technical Advisor (TA) for the program implementation at HMAS Cerberus (the Base).

The program is guided by information presented in the PFAS Management Area Plan (PMAP), which documents Defence's approach to investigating and managing risks to human health and the environment and impacts to Environmental Values from PFAS contamination associated with the Base.

The role of the TA is to conduct independent and critical review of investigation works and the management and mitigations measures implemented as part of any site remediation, as well as provide independent input to the program at the Base. The Site is defined to include the Base and Hanns Inlet Naval Waters, which is presented on Figure 1.1 below.

The purpose of this report is to provide a summary of the TA's independent review of the reports and information provided for review, as prepared by Defence's consultants, including:

- A summary of the TA's opinion on the final condition of the Site in relation to the level of risk posed to Environmental Values (i.e. the uses, attributes and functions of the environment that people value) by residual PFAS contamination following site redevelopment works and associated PFAS cleanup activities.
- A summary of the TA's opinion on how residual PFAS contamination is being managed on the Site.
- The TA's opinion on how the PMAP actions have been addressed.

The program includes an initial site characterisation phase to identify and/or assess:

- Sources of PFAS on the Base.
- The pathways by which PFAS mass discharged from these sources migrates towards receptors.
- The level of risk posed to those receptors by PFAS.

This initial work phase concluded that:

- Risks to human health and the environment off-Site are low and acceptable, with Environmental Values off-Site not detrimentally impacted.
- Risks to human health and the environment on-Site are low and acceptable, including for Defence personnel and intrusive maintenance workers operating in the fire training ground (FTG) with relevant Occupational Health and Safety (OHS) management measures being implemented.

Based on the initial site characterisation phase, no risk drivers were identified that would require remediation to achieve Defence's main objective of avoiding or minimising exposure to PFAS contamination from Defence property to human health and ecological receptors.

HMAS Cerberus was subject to a base redevelopment and upgrade program to improve Defence capability. Defence decided that opportunistic cleanup actions as part of the redevelopment should be taken to decrease PFAS mass discharge from the Base. The key cleanup actions included:

- Design and construct a containment facility at the FTG to encapsulate PFAS impacted source materials from the FTG, Ornamental Pond area and construction activities to decrease source mass discharge.
- Implementation of a long-term management plan that monitors and maintains the integrity of the containment cell and assesses ongoing PFAS mass discharge from the Site.

This report documents the TA's opinions on the robustness and defensibility of the data generated by the works and the management and mitigation measures undertaken as part of the program implementation, to provide an opinion of the final site condition to support Defence in the transition from a PMAP to long-term routine monitoring and management.

Based on the critical and independent assessment documented in this report, the TA is of the opinion that the management and mitigation measures implemented have achieved the cleanup objectives with respect to PFAS impacts and the program can move to a monitoring phase with contingency actions, implemented through an Ongoing Management Plan (OMP). All PMAP actions have therefore been addressed.

This report is subject to, and must be read in conjunction with, the limitations set out in Section 1.3 and the assumptions and qualifications contained throughout the Report.

Figure 1.1 *HMAS Cerberus site location (Aurecon 2023)*

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1. Introduction

Department of Defence (Defence) is undertaking a national program to investigate, manage and mitigate impacts of per- and poly-fluoroalkyl substances (PFAS) on, and in the vicinity of its bases around Australia. The goal of the program is to support affected communities and Defence capability by managing PFAS contamination through the adoption of best available science and practicable remedial/management approaches to restore or reduce impacts to Environmental Values.

1.1 Report purpose

The purpose of this report is to provide a summary of the Technical Advisor's (TA) independent review of the reports and information provided for review, as prepared by Defence's consultants, including:

– A summary of the TA's opinion on the final condition of the Site in relation to the level of risk posed to Environmental Values by residual PFAS contamination following site redevelopment works and associated PFAS cleanup activities.
– A summary of the TA's opinion on how residual PFAS contamination is being managed on the Site.
– The TA's opinion on how the PMAP actions have been addressed.

1.2 Background

The approach taken at each base is outlined in a PFAS Management Area Plan (PMAP), which documents Defence's approach to managing risks to human health and the environment and impacts to Environmental Values from PFAS contamination associated with the base.

A tailored approach is taken for each base due to the bespoke nature of PFAS contamination, the resultant risks and impacts to Environmental Values. An approach centres around either source control or pathway control, or a combination of both. Depending on the risk profile, prevention or minimisation of off-Site PFAS migration may be achieved through a remediation approach that can comprise active and passive management and mitigation measures including cleanup activities and ongoing monitoring.

Active management and mitigation measures refers to strategies that require active continual human intervention and continual energy inputs to operate effectively. Passive management and mitigation measures refers to strategies that do require occasional human intervention and limited or no energy input to function.

In 2018, Defence developed a PMAP (Australian Government Department of Defence 2018) for HMAS Cerberus (the Base) which incorporated the Base and Hanns Inlet, collectively defined as the Site. The PMAP is titled HMAS Cerberus, PFAS Area Management Plan, Revision 3 – 2 October 2018 (the PMAP) and can be found on the Defence website (**https://www.defence.gov.au/about/locations-property/pfas/pfas-management-sites/hmas-cerberus**).

For each site, Defence engages a Technical Advisor (TA) whose role is to provide independent input on the management and mitigation measures to be implemented through the PMAP and to critically and independently review work undertaken by Defence's consultants and contractors.

Where risks to human health and the environment are low and acceptable and Environmental Values are not adversely impacted by defined PFAS contamination at a Site (i.e., in the case of HMAS Cerberus), the TA is requested to provide an opinion on the final condition of the Site in relation to the objective of the work undertaken as part of the PMAP.

This report provides the TA's opinion on the final site condition of the Site in relation to the activities completed as part of addressing specific PMAP actions.

1.3 Report objectives

The objectives of this report are for the TA to provide an opinion as to whether:

– Sufficient robust and reliable data was collected to inform a defensible conceptual site model, identify any complete source, pathway and receptor linkages, establish relevant Environmental Values and support an assessment of risk to human health and the environment.
– The assessment of risk to human health and the environment and impacts to Environmental Values is robust and defensible enough to identify any elevated risks to human health and the environment and impacts to Environmental Values. Where risks were identified as low and acceptable and no detrimental impacts to Environmental Values was identified, assess whether sufficient information was available to support the decision to not undertake any active remediation to reduce that risk.
– Management and mitigation measures (i.e. cleanup activities) completed at the Site have reduced the PFAS mass discharge from the source areas (i.e. FTG and Fire Station/Ornamental Lake).
– A measurable reduction in PFAS mass discharge from the Site to the surrounding environment is evident as a consequence of the management and mitigation measures undertaken.
– Risks posed by residual PFAS impacts that remain on-Site remain low and acceptable or should further reduce over time.
– Passive ongoing management and mitigation measures are suitable to continue to prevent or minimise exposure to residual PFAS contamination.
– PMAP actions have been adequately addressed to transition the PMAP to a long-term environmental management program.

1.4 Limitations

This report: Final site condition HMAS Cerberus – PFAS Investigation and Management has been prepared by GHD for Department of Defence and may only be used and relied on by Department of Defence for the purpose agreed between GHD and Department of Defence as set out in Section 1.1 of this report.

GHD otherwise disclaims responsibility to any person other than Department of Defence arising in connection with this report. GHD also excludes implied warranties and conditions, to the extent legally permissible.

The services undertaken by GHD in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope limitations set out in the report.

The opinions, conclusions and any recommendations in this report are based on conditions encountered and information reviewed at the date of preparation of the report. GHD has no responsibility or obligation to update this report to account for events or changes occurring subsequent to the date that the report was prepared.

The opinions, conclusions and any recommendations in this report are based on assumptions made by GHD described in this report (refer Sections 10, 11 and 12 of this report). GHD disclaims liability arising from any of the assumptions being incorrect.

GHD has prepared this report based on information provided by Department of Defence and others who provided information to GHD (including Government authorities), which GHD has not independently verified or checked beyond the agreed scope of work. GHD does not accept liability in connection with such unverified information, including errors and omissions in the report which were caused by errors or omissions in that information.

GHD recognises that some documentation that contained information requiring the TA's verification was not available for review. GHD does not accept liability in connection with such unverified information and all opinions and conclusions in this report are made with the omission of this information.

2. Terms and definitions adopted

Terms and their definitions used in the preparation of this report are listed in Table 2.1.

Table 2.1 Terms and their definitions

Term	Definition of each term
Accredited or Appointed Environmental Auditor	An accredited or appointed auditor under State or Territory legislation.
Adopted Mass Estimate	The mass of PFAS compounds present in environmental media.
AFFF	Aqueous film forming foam
AS 18504-2022	AS 18504-2022 Sustainable Remediation
ASC NEPM	National Environment Protection (Assessment of Site Contamination) Measure 1999 (as amended 2013)
Base	A defined physical locality or geographical area from which Defence-related activities, operations, training or force preparations are managed, conducted, commanded or controlled. In this document, 'Base' refers to HMAS Cerberus.
CFI	Capital Facilities and Infrastructure Branch
Clean-Up	Active management and mitigation actions undertaken in response to addressing source-pathway-receptor linkages to decrease the impacts of PFAS on the environment. The objective of these actions is to either contribute to achieving the overall remediation goal for the base or where there is no driver for remediation to decrease the discharge of PFAS to the environment.
CSM	A Conceptual Site Model (CSM) is a representation and evaluation of contamination sources, the pathways by which contaminants can migrate, and the receptors (human health and/or ecosystems) that could be exposed to the contaminants. This information is used to identify the potential risks to human health and ecosystems.
Defence National PFAS Investigation and Management Program	The national program Defence is undertaking to investigate, remediate and manage impacts of per- and poly-fluoroalkyl substances (PFAS) on, and in the vicinity of its bases around Australia.
Detailed Site Investigation (DSI)	Detailed Site Investigation included investigation works that sample the environmental media, fauna and flora as necessary to identify and characterise the nature and extent of PFAS impacts in that environmental media.
EMOS	Estate Maintenance and Operations Services
Environmental Regulator	A State/Territory environmental regulator. May be named Environment Protection Authority or by a departmental name where those functions are embedded in a department.
Environmental Values	The uses, attributes and functions of the environment that people value.
Goal	The end point that active management and mitigation actions need to ultimately achieve (such as decreases risks to human health and the environment to low and acceptable levels and/or restoration of Environmental Values).
Human Health and Environmental Risk Assessment (HHERA)	Human Health and Environmental Risk Assessment, including consideration of human, flora and fauna receptors present in terrestrial and aquatic environments on and off-site. This assessment will identify the level of risk posed to receptors by PFAS presence in the environmental media to which the receptors are exposed.
LTEMP	Long-Term Environmental Management Plan
Mass Discharge (MD)	The mass of PFAS that is discharged from a source (primary (AFFF) and secondary (soil)) or within a pathway of migration (sediment, surface water and groundwater). The MD can be expressed in terms of mass (kg) per unit time (year) (kg/year).
Mass Flux (MF)	The speed at which PFAS mass moves along a pathway (sediment, surface water, groundwater). MF is generally expressed either in terms of mass (kg) per unit area per unit time (kg/m^2/year) or mass (kg) per unit volume (m^3) per unit time (years) (kg/m^3/year).

Term	Definition of each term
NEMP	PFAS National Environmental Management Plan (Version 2.0) (HEPA 2020). Please note, NEMP 3.0 was released in March 2025. This was after all assessment and cleanup works were completed. Therefore, the NEMP 2.0 document is relevant to this assessment.
NRF	Cooperative Research Centre for Contamination Assessment and Remediation of the Environment (CRC CARE), National Remediation Framework (NRF), August 2019.
Objective	The point at which active management and mitigation measures can cease as no further net environmental benefit can be achieved by continuing an action. Objectives generally aim to reduce SME, MF and MD to a specified level.
OMP	Ongoing Monitoring Plan/Program
Pathway Mass Discharge (PMD)	The mass of PFAS that moves along a particular pathway, at a particular location over time. This occurs primarily through the movement of sorbed phase in sediments and dissolved phase in water. The PMD represents the mass of PFAS that moves along a pathway to assist in prioritising management and mitigation actions towards meeting the remediation goal. The PMD can be expressed in terms of mass (kg) per unit time (year) (kg/year).
Pathway Mass Flux (PMF)	The mass of PFAS that moves across a unit area or volume of media along a pathway over time. This occurs primarily through the movement of sorbed phase in sediments and dissolved phase in water. The PMF can be measured over a planar area that sits across or the volume that moves within a migration pathway (primarily surface water and groundwater). PMF is generally expressed either in terms of mass (kg) per unit volume (m^3) unit time (year) (kg/m^3/year) or mass (kg) per unit area (m^2) per unit time (years) (kg/m^2/year).
PFAS	Per- and poly-fluoroalkyl substances
PFAS mass in environmental media	The amount of PFAS expressed in unit weight (kg) that resides in an environmental media, such as soil, sediment, groundwater, surface water. PFAS mass provides an indicator of where the contaminant mass resides and assists in planning active and passive management and mitigation actions.
PFHxS	Perfluoro-hexane sulfonate
PFOA	Perfluoro-octanoic acid
PFOS	Perfluoro-octane sulfonate
PMAP	PFAS Management Area Plan (and revisions)
Practicable Remediation Solution	A feasible and effective method for cleaning up contaminated sites, considering technical, economic and regulatory factors.
Primary Contamination Mechanism	The initial process by which contaminants are introduced into an environment, system or product.
Primary Contaminant Migration Processes	The ways in which contaminants move through different environmental media after initial release. For example, advection, diffusion, mechanical dispersion, sorption, biodegradation, volatilisation.
Preliminary Site Investigation (PSI)	Preliminary Site Investigation, including review of the activities that may have included use of PFAS containing products, identify where these products may have been used and establish whether any past works and infrastructure may have moved PFAS impacted media around the site.
Remediation	Active management and mitigation action undertaken in response to risks to human health and the environment and/or impacts to Environmental Values. These actions can include one or more clean-up actions that are undertaken on and off base to reduce risks to acceptable levels and restore Environmental Values. The remediation goal is to decrease risk to human health and the environment to low and acceptable levels and/or restore Environmental Values.
SFARP	So far as reasonably practicable
Site	In this document, a reference to ‘Site’ refers to the HMAS Cerberus and Hanns Inlet.
Source and source area	The source of PFAS at this Base is from AFFF. A PFAS source area can be defined as primary or secondary. Primary source areas are generally where AFFF was used or stored, secondary source areas are where contaminants may have accumulated in the environment.

Term	Definition of each term
Source Mass Discharge (SMD)	The mass of PFAS discharged by a source into the environment, primarily through leaching and migration along pathways (sediment, surface water, groundwater etc.) The emissions can be expressed in terms of mass (kg) per unit time (year) (kg/year). The SMD applies to each source present on a base and assists in identifying the priority for management and mitigation actions to address PFAS mass discharge.
SPR	Source Pathway Receptor
TA	Technical Advisor
Total mass discharge (TMD)	The total mass of PFAS that discharges from the site into the environment and is a combination of SMD and PMD. Understanding TMD sets a baseline prior to undertaking any management and mitigation actions and using TMD as a measurement of their success after implementation.

3. Decision-making framework

3.1 TA considerations regarding PFAS movement

When conducting the critical and independent review of the site characterisation, risk assessment, remediation, management and monitoring documentation for a site that emits PFAS to the environment, the TA considers how PFAS moves from the source to the receptor, with respect to the movement of PFAS mass. The movement of PFAS mass can be broken down into two important elements, the speed at which the mass moves and the amount of mass that moves. In the context of the source, pathway and receptor linkages, PFAS mass movement can be divided into the following key flux and discharge components, as set out in (Figure 3.1):

- Source Mass Discharge (SMD): Emission of PFAS from primary and secondary sources lead to PFAS entering the environment. Primary SMD occurred when PFAS containing products, such as AFFF foam used during training and active firefighting, discharge onto infrastructure and soils, which then becomes PFAS containing secondary sources. Secondary SMD occurs when PFAS is emitted from impacted infrastructure and soils etc. into the environment. Therefore, understanding where on a site SMD occurs is a critical step in managing and mitigating PFAS discharge into the environment. Management and mitigation of SMD can be divided into:
  - Monitor source(s), as active management and mitigation is not practicable due to the requirement for maintaining capability and capacity of the infrastructure on the site.
  - Manage source(s), through treatment of source materials to decrease SMD. SMD management generally involves containing the source (e.g., covering or encapsulating) or stabilising the source (e.g., activated carbon addition, etc.).
  - Mitigate source(s), through removal of source material to decrease SMD. SMD mitigation generally involves removal of the source material either through excavation and disposal at a suitable facility or excavation and treatment (e.g., thermal destruction, soil washing, etc.), followed by either disposal or reuse of the treatment material.
- Pathway Mass Flux (PMF): Movement of PFAS occurs along pathways that transmit PFAS from the source into the environment. Common pathways include sediment transport, surface water flow and groundwater movement. Understanding the circumstances and velocity at which PFAS mass moves along a pathway is an important consideration when planning management and mitigation measures to decrease PFAS mass discharge to the environment.
- Pathway Mass Discharge (PMD): PMF along pathways leads to PFAS mass discharge from the source into the environment. Understanding the PFAS PMD along a pathway is an important consideration when planning management and mitigation measures with the aim of decreasing PFAS mass discharge to the environment.
- Total Mass Discharge (TMD): TMD is the total mass of PFAS that discharges from the site into the environment and is a combination of SMD and PMD. Understanding TMD sets a baseline prior to undertaking any management and mitigation actions and using TMD as a measurement of their success after implementation.

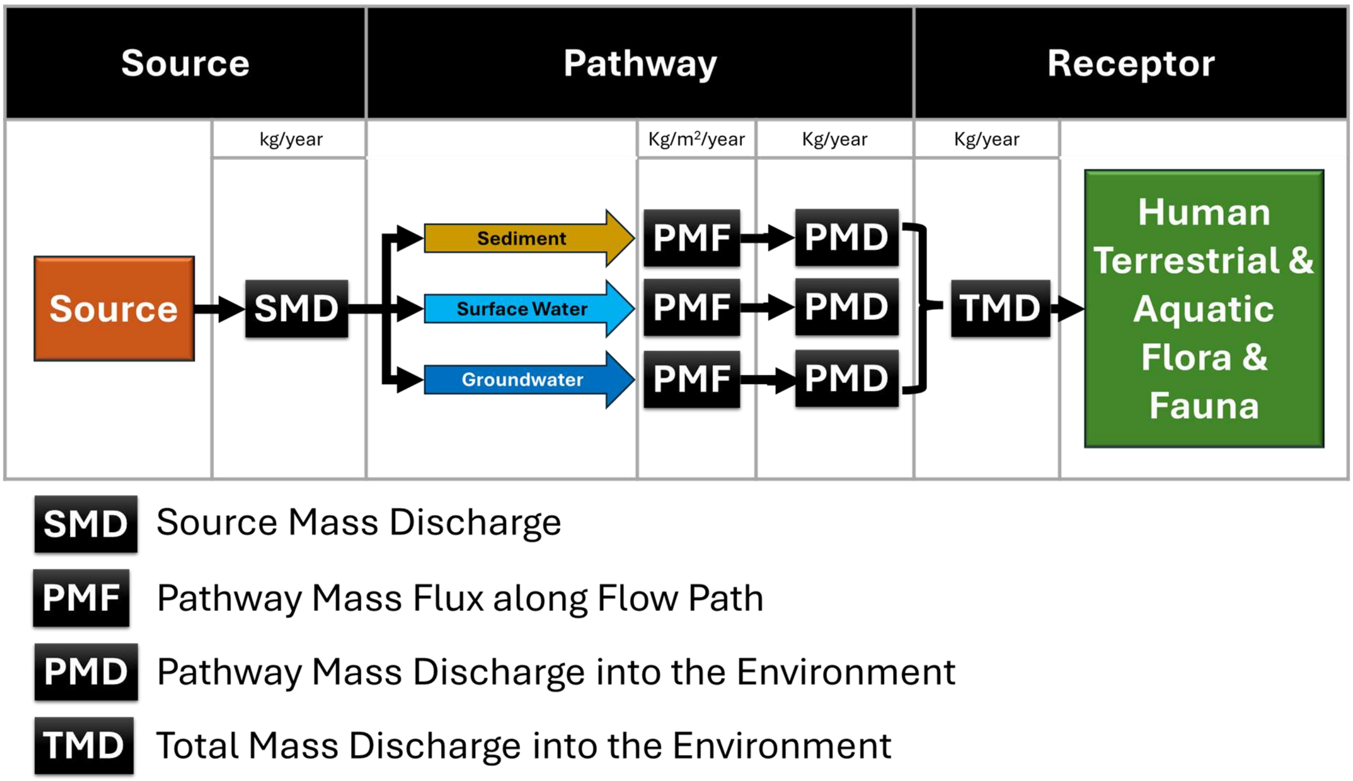


Figure 3.1 Conceptualisation of mass flux and mass discharge in the context of the source, pathway and receptors linkage.

3.2 TA workflow and decision process

To conduct an efficient and effective, critical and independent review of the investigation, management and mitigation actions, the TA mapped the general workflow and decision process. This mapping was done to identify the key gateway and decision points. At these points, the TA was requested to provide interim advice on whether the workflow can move forward.

The workflow and decision process set out in Figure 3.2 and further explained in Table 3.1, provides the main work phases and decision points considered necessary to progress a Site with suspected PFAS impacts to a reasonable and practicable endpoint.

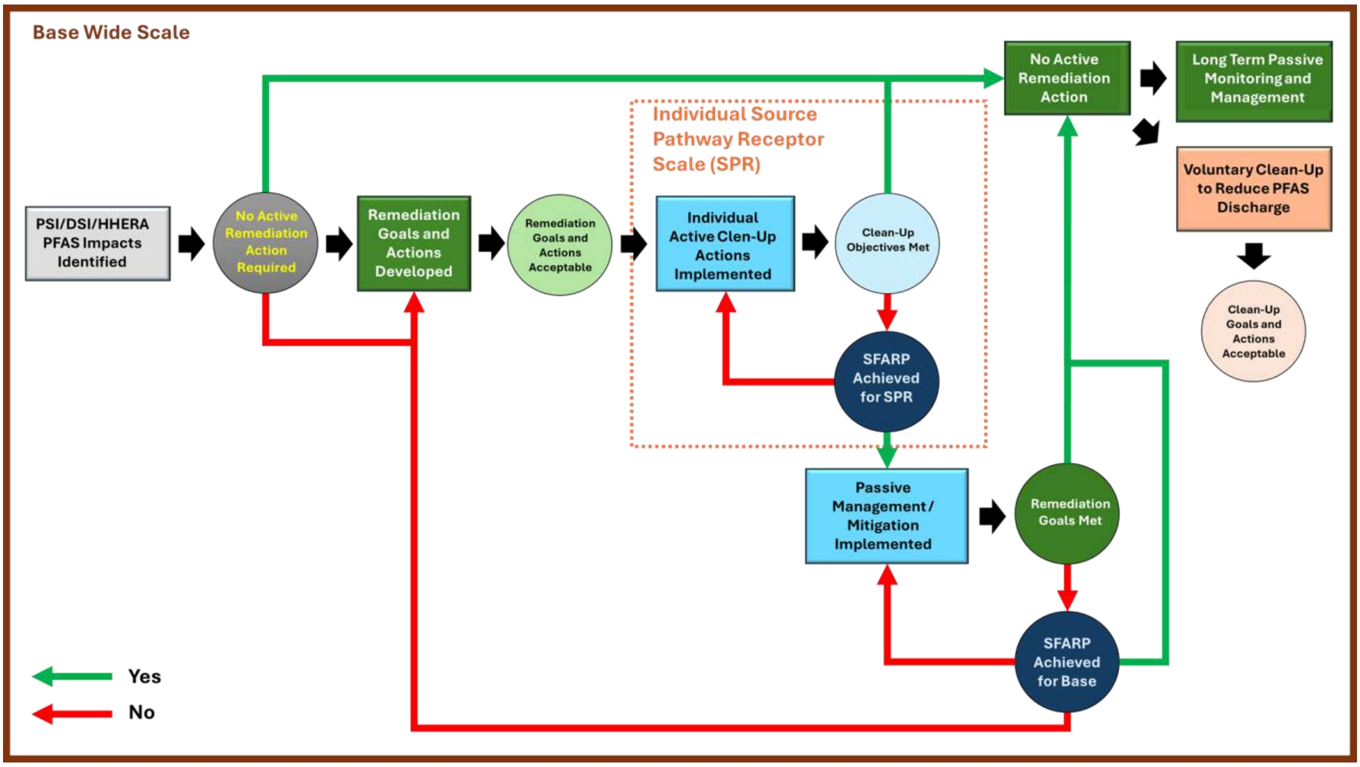
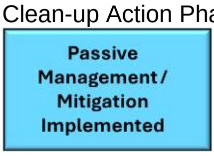


Figure 3.2 Conceptualisation of workflow and decision process.

Table 3.1 Breakdown of workflow and decision process

Phases and decision points	Description
Site Characterisation Phase 	Characterisation and assessment of risk related to historical use of PFAS containing products at the site. The work tasks commonly associated with this work phase include completion of a PSI, DSI and HHERA. The information from this work phase will inform a decision on whether active remediation actions are required to manage and mitigate impacts associated with PFAS impacts.
Further Action Decision Point 	The first key decision point in the workflow is whether active remediation actions are required to decrease risks to low and acceptable levels and /or restore Environmental Values. The details of the process adopted by the TA to support this decision are set out in Table 3.2.
Remediation Goals Setting and Action Planning Phase 	Once the decision that active remediation actions are required to decrease risk and /or restore Environmental Values is made, the next work phase involves: – Development of remediation goals that focus on decreasing risks to low and acceptable levels and restores Environmental Values. – Identify, develop and plan feasible active remediation actions that provide the most practicable and effective means to meet the remediation goal.
Remediation goal and action Decision Point 	After completion of the remediation goal setting and action planning the next key decision point is whether the remediation goals set, and actions planned are appropriate and practicable. The details of the process adopted by the TA to support this decision are set out in Table 3.2.

Phases and decision points	Description
Implementation of Individual Active Clean-up Action Phase 	Remediation generally comprises one or more distinct cleanup actions that need to be implemented in order to achieve the overall goals of the remediation. Each individual cleanup action aims to achieve a specific objective and represents a distinct part of the overall remediation strategy implemented at the site.
Clean-up Objectives met Decision Point 	After implementation and completion of the clean-up action(s), the next key decision point is whether the set cleanup objectives have been met. The details of the process adopted by the TA to support this decision are set out in Table 3.2.
Clean-up Action SFARP Decision Point 	Where the objectives set for the cleanup actions are not achieved within reasonable technical, logistical and financial effort and sustainability considerations, the next key decision point is whether the clean-up has achieved a practicable end point, and no net environmental benefit would result from continuing the clean-up action. The details of the process adopted by the TA to support this decision are set out in Table 3.2.
Implementation of Individual Passive Clean-up Action Phase 	Once active cleanup actions have either met the clean-up objectives or have been implemented SFARP, passive cleanup actions must be implemented to deal with any residual PFAS impacts. The aim of the passive cleanup actions is to minimise risks to human health, the environment and Environmental Values SFARP into the future.
Remediation Goals Met Decision Point 	After implementation and completion of the remediation, the next key decision point is whether the remediation goals set, and actions undertaken, have been met. Details of the process adopted by the TA to support this decision are described in Table 3.2.
Remediation Action SFARP Decision Point 	Where the remediation goals are not achieved within reasonable technical, logistical and financial effort and sustainability considerations, the next key decision point is whether the remediation has achieved a practicable end point, and no net environmental benefit would result from continuing the remediation. The details of the process adopted by the TA to support this decision are set out in Table 3.2.
No Further Active Remediation Action Phase (Passive Management Phase) 	When no active remediation actions are needed to reduce risk or restore Environmental Values, or when the remediation goals have been achieved, the project will transition to long-term management and monitoring to address any remaining PFAS impacts.
Long Term Passive Monitoring and Management Phase 	Once active remediation has ended the site can transition to Long-Term Environmental Management that deals with any residual PFAS impact that remain after completion of remediation.

Phases and decision points	Description
Voluntary Clean-up Action Phase Voluntary Clean-Up to Reduce PFAS Discharge	In situations where no further active remediation is required, either due to risks being low and acceptable, Environmental Values having been restored or remediation goals having been met SFARP, some clean-up actions may still be implemented on a voluntary basis to further decrease mass discharge of PFAS into the environment.
Voluntary Clean-up Objectives and Action Acceptable Decision Clean-Up Goals and Actions Acceptable	After completion of the Site Characterisation Phase or when No Further Active Remediation Action is required, further cleanup action may be undertaken to achieve goals on a voluntary basis using actions to achieve those goals. Therefore, the next key decision point is whether the cleanup goals set, and actions planned are appropriate and practicable. The details of the process adopted by the TA to support this decision are set out in Table 3.2.

3.3 Data quality objectives

To facilitate a structured and consistent approach to the TA review process, the Data Quality Objectives (DQO) set out in Table 3.2 were adopted. The DQO Process involves logical steps that guide the TA's review. This ensures a resource-effective approach to conduct an independent advisory role for completing PMAP implementation and transitioning to long-term management. The DQO Process is both flexible and iterative, and applies to both decision-making (e.g., compliance/non-compliance with a standard) and estimation (e.g., ascertaining the mean concentration level of a contaminant, assessment of risk, impact to Environmental Values, effective management and mitigation measurements).

The DQO Process is used to establish performance and acceptance criteria, which serve as the basis to independently support robust and defensible decision making for implementation of the PMAP and process for transition from PMAP to long-term management. Use of the DQO Process leads to:

- Efficient and effective expenditure of resources.
- A consensus on the type, quality, and quantity of data needed to meet the project goal.
- Full, clear and transparent documentation of actions taken during the development of the project.

Table 3.2 Data Quality Objectives Process

<table>
<tr><th>Step</th><th colspan="2">Description</th></tr>
<tr><td>Step 1. State the Problem</td><td colspan="2">Has the historical use of PFAS containing products, particularly AFFF, resulted in impacts to Environmental Values on and off base? Do these impacts warrant remediation (i.e., active management and mitigation actions) to reduce risk to Human Health and the Environment (characterised through an HHERA) to acceptable levels? Where required, have these active actions restored Environmental Values and decreased risks to low and acceptable levels?</td></tr>
<tr><td rowspan="4">Step 2. Identify to the Decision of the Assessment</td><td colspan="2">As part of the review of the PMAP process with respect to the problem statement (Step 1) requires the following decisions by the TA:</td></tr>
<tr><td>No Active Action Required</td><td>Have the DSI and HHERA demonstrated that impact from one of more sources of PFAS emissions do not impact Environmental Values, and risks to current and potential future receptors on and off base are low and acceptable?</td></tr>
<tr><td>Remediation Goals and Actions Acceptable</td><td>Are the remediation goals and remediation methods of active management and mitigation actions reasonable and, the actions proposed, able to reduce risks to human health and the environment to low and acceptable levels and restore Environmental Values?</td></tr>
<tr><td>Clean-Up Objectives Met</td><td>Have the objectives of the active cleanup management and mitigation measures undertaken with respect to the source(s), pathway and receptor linkages reduced PFAS discharge into the environment and reduced exposure?</td></tr>
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Step	Description	
	SFARP Achieved for SPR	Where the active management and mitigation measures have not been able to reduce risk to human health and the environment to low and acceptable levels and /or restore Environmental Values, have actions undertaken been able to meet the objectives of SFARP with respect to Source, Pathway and Receptor (SPR) linkages?
	Remediation Goals Met	Have the goals of the remediation undertaken with respect to the base and surrounding environment been met?
	SFARP Achieved for Base	Where the remediation has not been able to ultimately meet the objectives, have actions undertaken been able to meet the objectives SFARP with respect to the base and surrounding environment?
	Clean-Up Goals and Actions Acceptable	Have the objectives of the active clean-up management and mitigation measures undertaken with respect to the source(s), pathway and receptor linkages reduced PFAS discharge into the environment and reduced exposure?
Step 3. Identify Information Inputs to support Decisions	The key information required by the TA to support the decisions made as part of the review process are: – Information on where and when potentially PFAS containing products, particularly with respect to use of AFFF, occurred on the base. – Preliminary and Detailed Site Investigation Data (PSI/DSI) that characterise the following as far as reasonably practicable: • Geomorphological setting of the base and surround (geology, hydrology, hydrogeology, geochemistry and hydrochemistry, etc.). • Sources (primary, secondary and tertiary) where PFAS is present and where emissions occur from the base into the environment. • Pathways (Air, Soil, Sediment, Surface Water, Groundwater) by which PFAS emission from source areas migrate into the environment and expose receptors. – Receptors (human, terrestrial and aquatic flora and fauna) that may be exposed currently or in the future to PFAS emissions from the source areas on the base. – Human Health and Environmental Risk Assessment that characterises the nature, scale and acceptability of risks arising from PFAS exposure to human, terrestrial and aquatic flora and fauna receptors. – Remediation Action Plan (RAP) that sets out the objective of the active management and mitigation measures selected as suitable and effective to be implemented with respect to the SPRs to achieve the goals set for the remediation of the base. – Management and Mitigation Action Validation Report(s) that provide robust and defensible data for multiple lines of evidence that demonstrate that the actions undertaken have achieved the objectives. Where the objectives were not met, a sound and robust multiple lines of evidence case is required to demonstrate that the active management and mitigation measures have progressed towards achieving the objectives SFARP. – Ongoing Management Plan (OMP) that monitors the emissions of PFAS into the environment and provides data with respect to the performance of the active and passive management and mitigation measures with respect to progress towards achieving the remediation goals. – Remediation Validation Report (RVR) that provides robust and defensible data for multiple lines of evidence, that demonstrate that the actions undertaken have achieved the remediation goals. Where the remediation goals were not met, a sound and robust multiple lines of evidence case is required to demonstrate that the active and passive actions have progressed towards achieving the remediation goals SFARP. – Long-Term Environment Management Plan (LTEMP) that sets out the monitoring, management and contingency measures to be implemented over the long term after active management and mitigation of PFAS impacts cease.	
Step 4. Define the Boundaries of the Assessment	The boundaries of the assessment area are defined in the PMAP.	

<table>
<tr><th>Step</th><th colspan="2">Description</th></tr>
<tr><td>Step 5. Develop the Analytical Approach</td><td colspan="2">The following analytical approach was adopted for the review of the PMAP implementation process with respect to remediation:
– The source of all public database and anecdotal information supplied is clearly identified and verified.
– All sampling and analytical analysis undertaken as part of all investigation, remediation, validation and monitoring works was collected using robust and defensible methods.
– All analytical data was of suitable accuracy and precision, thereby demonstrating suitable reliability to support defensible risk assessment and decision making.
– Risk assessments with respect to human, terrestrial and aquatic flora and fauna receptors was undertaken using robust and defensible methods that relied on robust and verified data.
– Management and Mitigation methods adopted to address impacts to Environmental Values, including risks to human health and the environmental receptors are robust, defensible and provide the best opportunity to achieve the cleanup objectives and overall remediation goals.
Validation of the active management and mitigation measures demonstrates that:
– The objectives of the actions have been met and there is no rebound.
– Where the objectives could not be met, that actions have progressed towards achieving the objectives SFARP and no further net environmental benefit would be achieved by undertaking further active management and mitigation measures.
– Ongoing monitoring demonstrates the status of any residual PFAS impacts that remain in a robust and defensible manner.
Validation of the remediation works demonstrates that:
– The goal of the remediation works has been met and there is no rebound.
– Where the goal could not be met, that actions have progressed towards achieving the goal SFARP and no further net environmental benefit would be achieved by undertaking further active management and mitigation actions.
– Long-term monitoring and management actions are reasonable and effective at managing any residual PFAS impacts on site and any associated residual emissions to the environment are stable or preferably declining over the long term.</td></tr>
<tr><td rowspan="3">Step 6. Specify Performance or Acceptance Criteria</td><td colspan="2">To support robust and defensible decision making over the course of the review process, the following performance criteria were adopted:</td></tr>
<tr><td>No Active Action Required</td><td>The specified performance or acceptance criteria for this decision point are:
– The robustness and defensibility of the data used to support decision making meets the relevant Quality Assurance (QA) and Control Data Quality Indicators (DQI).
– PFAS exposure concentration for relevant receptors are demonstrated to be below the Tier 1 risk screening criteria at the 95% confidence level. Or where this is not the case – risks posed to receptors by PFAS are low and acceptable as demonstrated through a robust and defensible HHERA.</td></tr>
<tr><td>Remediation Goals and Actions Acceptable</td><td>The specified performance or acceptance criteria for this decision point are:
– The robustness and defensibility of the data used to support decision making meets the relevant QA and DQIs.
– The sources, pathways and receptors, including the linkages between them have been adequately characterised to inform development of defensible remediation goals.
– The remediation goals set for the base are clearly stated and meet the spirit and intent of Commonwealth and State legislation.
The remediation management and mitigation actions (comprised of one or more clean-up actions) provide the most appropriate means of achieving the remediation goals for the site, having considered:
– Technical feasibility and performance of remediation measures is demonstrated through appropriate research, laboratory trials and field trials.
– Logistical requirements for implementation of the remediation measures are commensurate to the risk to human health and the environment, impact to Environmental Values and maintain capability and operations of the site.
– Financial investment for implementation of the remediation measures are commensurate to the risk to human health and the environment, impact to Environmental Values and demonstrate prudent expenditure of public funds.</td></tr>
</table>

Step	Description	
		– The remediation goals and actions aim to achieve a net environmental benefit.
	Clean-Up Objectives Met	The specified performance or acceptance criteria for this decision point are: – The robustness and defensibility of the data used to support decision making regarding the clean-up actions meets the relevant QA and DQIs. – The sources, pathways and receptors associated with the risks to human health and the environment and /or impacts to Environmental Values have been adequately characterised to inform development of defensible clean-up objectives for the individual clean-up actions that contribute to achieving the remediation goals for the site. The cleanup actions provide the most appropriate means of achieving the remediation goals for the site, having considered: – Technical feasibility and performance of each cleanup action is demonstrated through appropriate research, laboratory trials and field trials. – Logistical requirements for implementation of each cleanup action are commensurate to the risk to human health and the environment, impact to Environmental Values and maintain capability and operations of the site. – Financial investment for implementation of each cleanup action is commensurate to the risk to human health and the environment, impact to Environmental Values and demonstrate prudent expenditure of public funds.
	SFARP Achieved for SPR	The specified performance or acceptance criteria for this decision point are: – The robustness and defensibility of the data used to support decision making meets the relevant QA and DQIs. – The clean-up action, while not meeting the clean-up objective, has resulted in: • A decrease in TMD and /or PMD and PMF. The cleanup actions were implemented within the: – Technical specifications and have achieved a practicable end point with respect to progress towards achieving the clean-up action objective. – Logistical constrains and capabilities of the clean-up action undertaken but continuance of the action would result in an interference with capability and operations of the site. – Financial expenditure has been commensurate with the scale, extent and magnitude of the cleanup objectives towards achieving the clean-up goals and further implementation of the cleanup action(s) results in a diminishing return on investment.
	Remediation Goals Met	The specified performance or acceptance criteria for this decision point are: – The robustness and defensibility of the data used to support decision making meets the relevant QA and DQIs. – Remediation actions undertaken have achieved the remediation goal(s) set for the site.
	SFARP Achieved for Base	The specified performance or acceptance criteria for this decision point are: – The robustness and defensibility of the data used to support decision making meets the relevant QA and DQIs. – The remediation actions, while not meeting the remediation goal, has resulted in a decrease in TMD from the site. – The TMD from the site shows a decreasing trend at an acceptable level of statistical confidence. The remediation actions were implemented within the: – Technical specifications for the remediation method(s) and have achieved a practicable end point with respect to progress towards achieving the remediation goal. – Logistical constraints and capabilities of the remediation actions undertaken and have reached a point where continuance of the action would result in an interference with capability and operations of the site. – Financial expenditure, commensurate with the scale, extent and magnitude of the remediation actions towards achieving the remediation goals and further implementation of the remediation action(s) would result in a diminishing return on investment.

Step	Description
	Clean-Up Goals and Actions Acceptable The specified performance or acceptance criteria for this decision point are: – The robustness and defensibility of the data used to support decision making in regard to the clean-up actions meets the relevant Quality Assurance and Control Data Quality Indicators (DQI). – The sources, pathways and receptors associated with the TMD to the environment have been adequately characterised to inform development of defensible clean-up objectives for the individual clean-up actions intended to reduce TMD to the environment. The clean-up actions provide the most appropriate means of achieving the clean-up objectives, having considered: – Technical feasibility and performance of each clean-up action is demonstrated through appropriate research, laboratory and field trials. – Logistical requirements for implementation of each clean-up action are commensurate to the TMD from the site and maintain capability and operations of the site. – Financial investment for implementation of each clean-up action is commensurate to the TMD decrease and demonstrate prudent expenditure of public funds.
Step 7. Develop the Plan for Obtaining the Data to Support the Assessment	To complete the TA role for the site, the following plan was developed to deliver the critical and independent review of documentation and complete advice to support transition of the PMAP for the site: – Establish clear and concise DQIs for assessment of data generated to support site characterization and remediation decisions. – Provide clear and concise feedback and comments on documents that are critically and independently reviewed by the TA and his team. – Review and approve clear and concise remediation goals that consider the risk to human health and the environment, impacts to Environmental Values, Commonwealth environmental legislation and compliance with the spirit and intent of State environmental legislation. – Review and approve clear and concise clean-up objectives for the clean-up actions to be implemented as part of the overall remediation approach for the site. – Achieving the remediation goal is demonstrated using multiple lines of evidence, supported by robust and defensible data that is presented in a clear and concise Remediation Validation Report (RVR). – Achieving the clean-up objectives is demonstrated using multiple lines of evidence, supported by robust and defensible data that is presented in a clear and concise Clean-up action close out report (CCR). – Demonstrate that Remediation SFARP has been achieved for the site based on technical, financial, logistical and sustainability considerations and no net environmental benefit would be achieved by further active remediation actions. – Demonstrate that Clean-Up SFARP has been achieved for the source, pathway and/or receptor based on technical, financial, logistical and sustainability considerations.

3.4 Assessment and restoration (where necessary) of Environmental Values

Environmental Values are the uses, attributes and functions of the environment that people value. Environmental Values include those associated with the land environment, surface water, groundwater, ambient air, ambient sound and sediments. The Environmental Values concept was introduced by the Victorian Government. As Defence has a policy of considering state legislation in both spirit and intent, this was taken into account by the TA during the preparation of this report.

The Victorian Government Environment Reference Standard, 2021 (ERS), which forms part of subordinate legislation of the Victorian Environment Protection Act 2017, defines the Environmental Values and sets the objectives for supporting different uses of the environment and indicators that can be measured to establish whether those objectives are being met. The indicators and objectives provide a basis for assessment and reporting on environmental conditions in Victoria.

Restoration and/or maintenance of Environmental Values can be achieved through prevention, management and/or mitigation of unacceptable/elevated risks posed to the Environmental Values, which may include active cleanup activities or passive monitoring activities. It is recognised that all or some Environmental Values may not be able to be restored within a foreseeable timeframe event with active intervention. In such cases the legislated standards cannot be met due to impracticalities posed by one or more site characteristics, such as technical, logistical, financial and also sustainability considerations. However, efforts should be made to restore the Environmental Values to the extent practical.

Risks to Environmental Values is the primary driver for active remediation. If there is no unacceptable risk posed to Environmental Values, no remediation is required. However, in Victoria, there is a legislated general environmental duty (GED) requiring each Victorian and all businesses to manage activities to reduce the risk of harm:

– To human health and the environment.
– From pollution or waste.

HMAS Cerberus and all Defence estates across Australia operate on Commonwealth land. Therefore, State and Territory legislation is not enforceable on Defence estates. However, Defence has an obligation to all personnel and communities to manage and reduce risks to human health and the environment where practical. Defence has regularly involved EPA Victoria through the PMAP implementation process.

Defence has adopted a remediation SFARP process which details how a risk-based approach to restoring Environmental Values can be applied for Defence estates impacted by PFAS.

In the case of HMAS Cerberus, the DSI and HHERA did not identify any unacceptable risk to Environmental Values posed by PFAS contamination on the Site, therefore active remediation was not required. Instead, a proactive management and mitigation program including some targeted source zone cleanup at the FTG was employed, with the objective of improving the quality of Environmental Values (refer to Section 8) and meeting the GED.

4. Site characterisation phase findings

This section of the report sets out the findings of the site characterisation phase of the works. This information supported the first key decision point, whether remediation was required to decrease risks to low and acceptable levels and/or restoration of Environmental Values was required.

4.1 Site description

The Site is located approximately 70 km south of Melbourne, Victoria. It is situated between Somers and Bittern/Crib Point and directly surrounds Hanns Inlet on the north arm of Western Port Bay.

Various facilities were present on the Site that service four tri-service (Army, Air Force and Navy Personnel) schools (i.e. Recruit School, School of Sea Survivability, Physical Training Instructor School, Defence Force School of Signals) and include uses for training, recreation and temporary accommodation in the main operating area (Australian Government Department of Defence 2024; Aurecon 2018). The eastern arm of the Site contains permanent residential areas, a golf course and childcare centre (Aurecon 2018). Surrounding land uses are varied, including residential, industrial, natural bushland and urban reserves. Activities in the surrounding area include petroleum storage and processing, fishing, fire tugboat berthing and support facilities, agriculture, recycled water treatment facilities, and the former Crib Point Municipal Landfill (Aurecon 2018). Figure 4.1 from Aurecon 2021, depicts land uses, land features and the Base boundary in yellow outline.

Figure 4.1 Site Details (Aurecon 2021)

4.2 Geomorphological setting

The Site is located within a broad coastal valley catchment area. The elevation of the Site varies between 0 metres Australian Height Datum (m AHD) and 10 m AHD in the main operational area, which is flanked by two tidal flats (Aurecon 2022). As the Site is situated in a topographical low point in the catchment area, the general flow direction of surface water and shallow groundwater from surrounding land is towards the Site, ultimately discharging into Western Port Bay which is a key environmental receptor. Western Port Bay is a RAMSAR listed wetland and protected under the international convention (Aurecon 2018).

Two local creeks (East Creek and South Creek) transect the Site and border the main operational area, a third creek (West Creek) enters the site south of the former Sewage Treatment Plant (STP) (Aurecon 2021). South Creek runs in proximity south of the Former FTG and East creek comprises two tributaries originating off-Site, north of the Fire Station and discharges to Hanns Inlet (Aurecon 2021). These surface water flows are considered a key pathway of PFAS migration off the Site from primary sources (outlined in Section 4.9) The local topography of the Site slopes to the south east direction and runoff from the Site surface waters and creek flows ultimately discharge to Hanns Inlet, which forms an estuary with Western Port Bay.

Higher ridges are present on-site (approximately 20 m AHD) and include remnant vegetation in the north and south direction of the two main drainage channels.

4.3 Climate

Climate data at the Site has been monitored by the Bureau of Meteorology at the HMAS Cerberus weather station (#086361) since 1986 (Aurecon 2021). Climate data is used to assist in the interpretation of groundwater recharge, channel and creek flow response to stormwater inputs, storm event monitoring, and evaluating monitoring data within a historical context.

Historical average rainfall was reviewed by Aurecon (Aurecon 2021); monthly rainfall was found to be high from the months May to August with a monthly average between 71 and 76 mm. In contrast, February was considered the driest month on average with a low monthly rainfall of 38 mm. During periods of high rainfall and storm events, PFAS can be mobilised through surface water runoff and surface water body overflow (e.g. creek, dams). This water then discharges into other sensitive environments such as wetlands, estuaries, local water channels, reaching wider areas of water catchments.

The average minimum and maximum temperatures for the area were reported as 6ºC and 14ºC, respectively, in the winter season and 14ºC and 25ºC, in the summer season. The average annual windspeed was measured at approximately 15 km/h in the morning and reached 20 km/h during afternoon monitoring (Aurecon 2018). PFAS can be transported through mobilisation of airborne contaminated soils. This is more likely to occur during dry, windy periods.

4.4 Geology

Geological mapping of the Western Port Bay area indicated that the geology of the Site was primarily comprised of Red Bluff Sandstone and included coastal dune deposits, coastal lagoon deposits, and the Mornington Volcanic Group (Aurecon 2018). Organic matter availability, clay mineralogy and oxide minerals (primarily iron and aluminium) availability vary within geological deposits and influences sorption of PFAS. Sorption of the non-charged Carbon-Fluorine end of the aliphatic chain to organic matter, primarily occurs through hydrophobic processes. Sorption of the charged end (cationic, anionic and zwitterionic) to negatively charged clay and oxide mineral surfaces occurs primarily through electrostatic processes, either through direct attraction or through a bridging ion.

Site geology, encountered during intrusive investigations, generally consisted of orange-brown, firm-stiff clay to 6-7 metres below ground level (m bgl), underlain by sandy clays to clayey sands to 12 m bgl (Aurecon 2022). This sediment distribution is considered reflective of variable conditions typical of fluvial depositional environments in the Brighton Group sediments (localised sandy channels within dominant clay soils). Fluvial systems are considered the primary receiving area for surface water and provide habitat for marine fauna and flora.

In the main operations and residential areas of the Site, up to 3 m of alluvium had been deposited over recent geological time periods (centuries to millennia) in shallow drainages between ridges of faulted Tertiary Brighton Group Sediments (Aurecon 2018).

Alluvial/estuarine delta deposits of grey-black silts and clays occurred within the tidal zone up to 2 m depths and are primarily situated in the mangrove swamps and salt marshes south and east of the operational portion of the Site (Aurecon 2018).

4.5 Hydrology

Three creeks (South Creek, West Creek and East Creek) are present on the Site and are responsible for draining the area to Hanns Inlet which is set within tidal flats (Aurecon 2021). The upper reaches of these creeks are intermittent (ephemeral) above the tidal zone (Aurecon 2021). The water depth at Hanns Inlet varies with tide fluctuations; water levels at high tide can reach up to 2 m, while the tidal flats are often exposed during low tides. Water levels follow a semi-diurnal tidal cycle which can typically see the tidal flats inundated twice a day (Aurecon 2021).

Surface water on the Site primarily discharges to Hanns Inlet via local creeks (South Creek, West Creek and East Creek) or through stormwater systems and outflows. Several drains were located topographically up-gradient of the Site, along the northern and western site boundaries. The general topography of the Site indicates surface water flows in a southeast direction (away from off-site residents) (Aurecon 2018; 2021).

Man made open drains, and an engineered concrete pit and pipe network comprise the primary stormwater management network in the operational area of the Site. Redevelopment and replacement of deteriorated stormwater infrastructure was conducted and included the installation of bioretention basins at six stormwater mains that are preceding the outfalls into the wetlands of Hanns Inlet. Tidal influence on water levels were reported by Base staff and backflow occurring from the outlets was observed during periods of high tide, resulting in filling of the basins (Aurecon 2021). Plans of the historical stormwater drainage network are presented in Aurecon 2021. Updated service plans have not been provided by Defence.

A channel between 2 m and 3 m deep has been constructed to connect the Base with Hanns Inlet, providing access for ships. The access channel is maintained via dredging of weeds and marine vegetation and the spoil has historically been placed in the Sullage Pit (Aurecon 2022).

4.6 Hydrogeology

Groundwater at the Site generally flows in a southerly or easterly direction and discharges directly into Hanns Inlet and Western Port Bay. Quaternary alluvial sediments form the hydrostratigraphic unit at the Site and surrounding area. Silts and clays comprise the primary alluvial sediments of the groundwater system which also includes localised channel deposits of sands and gravels. These coarser grained sediments are consistent with high energy channelised flows and are likely to provide preferential flow pathways for groundwater (Aurecon 2021). A groundwater system with high organic matter content, clay and oxide mineral availability may provide greater opportunity for attenuation of PFAS (Newell et al. 2021).

However, changing pH levels can influence the fate and transport of the contaminant, and a reduction in pH can drive anionic PFAS release from sorption sites and subsequently move more readily into groundwater. Further, sorption of PFAS at the water/water interface is generally less effective than the air/water interface, resulting in generally higher mobility of PFAS in the saturated zone than the unsaturated zone (ITRC 2023).

Groundwater is expected to discharge via evapotranspiration, or surface water interactions such as local drains and Hanns Inlet. Groundwater is typically found within 20 m bgl and standing water levels indicated a vertical upward gradient between the Tertiary Brighton Group sediments and overlying Quaternary alluvial sediments, suggesting some limitations to vertical downward migration of PFAS impacts. Shallow groundwater is likely to be primarily recharged directly through rainfall in the catchment area. Groundwater recharge may also be occurring on the Site via the irrigation of sports fields and agricultural land utilising municipal water supply, the storage pond at the former FTG, and leaky mains, to a lesser extent (Aurecon 2021; 2022).

Saline groundwater was detected in shallow wells installed in alluvial/estuarine sediments in the wetlands near South Creek, and in fill material in the marina area. A review of electrical conductivity (EC) values in Aurecon 2018 indicated seawater intrusions to areas of fill material which was expected to overlie fresher (brackish) groundwater within the uppermost Brighton Group Aquifer. Clay layers within and between the Quaternary alluvial sediments and Tertiary Brighton Group sediments have resulted in perched groundwater systems and semi-confined conditions of the aquifer (Aurecon 2018).

In addition, modelled groundwater contours suggested a presence of localised groundwater mounds at and around the FTG (CSR_VIC_000276), former petrol station (CSR_VIC_000279), closed Rifle Range Road landfill (CSR_VIC_000137), and the Sports Field (Aurecon 2018). These mounds coincide with decreased EC values. This indicates localised surface water infiltration zones associated with these land use areas. Increased infiltration of surface water through PFAS mass in soil will result in increased leaching of PFAS to the underlying groundwater Brighton Group Aquifer.

Across the Site, groundwater salinity, as a measurement of total dissolved solids (TDS), falls within the groundwater Segment B (1,000 mg/L and 3,500 mg/L TDS) (Aurecon 2018; VVG). This indicates that groundwater in the area is generally not suitable for potable use, and no use of groundwater is known at the Site (Aurecon 2018).

Seawater intrusion occurs near tidal channels. A wedge of saline groundwater is expected to extend to the west of Hanns Inlet and near the tidal channels south and east of the operational area of the Site, along the shoreline (Aurecon 2021). In the tidal flats, seawater recharges the surface sediments along with shallow groundwater in a mixing (hyporheic) zone. This means that there may be some recirculation of groundwater containing PFAS to surface water and returning into groundwater. However, there are three major effects that can reduce the flux of PFAS into surface waters of Hann Inlet:

– Tidal effects causing discontinuous discharge of impacted groundwater.
– The large dilution factor as groundwater mixes with seawater.
– The ‘salting-out’ effect whereby the solubility of PFAS decreases by orders of magnitude upon discharge of fresher water to saline water. This can result in partitioning of PFAS to the solid (sediment) phase from the dissolved aqueous phase (Pan and You 2010).

Given these factors, it is considered that direct discharge of PFAS via the groundwater pathway will result in a negligible contribution to PFAS mass discharge from the Site.

4.7 History of AFFF use and associated PFAS contamination characterisation

The Site was acquired by the Commonwealth Government in 1911 and developed into the Royal Australian Navy (RAN) Flinders Naval Depot. In 1921, the Site became the RAN training base, known as HMAS Cerberus. Training activities involving the use of aqueous film-forming foams (AFFF) were undertaken at the RAN School of Survivability and Ship Safety (SSSS) facility, specifically the Fire Training Ground (FTG) during the 1970s to approximately 2008.

In October 2018, Defence conducted detailed investigations into potential PFAS contamination at the Site and an evaluation of risk to human health and the environment and to assess impacts on Environmental Values on and around the Site (Aurecon 2018). The investigations found PFAS concentrations primarily in areas where AFFF had been historically used for firefighting, storage, or disposal. Key source areas consisted of the (Aurecon 2018):

– Fire Training Ground (Royal Australian Navey (RAN) School of Ship Safety and Survivability (SSSS) & South Creek wetlands.
– Fire Station Area (FSA) & Ornamental Lake.
– Former Sewage Treatment Plant.
– Sullage Pit.
– Potential minor sources in soil and sediments.

PFAS has been identified in other areas of the Site at low levels in soils, groundwater, and surface water. PFAS has been mobilised on the Site through surface water flowing through drains and creeks or in groundwater that infiltrated through soils and rock. These were considered the primary pathways for PFAS mobilisation and migration (Aurecon 2018) by which PFAS discharges from the site. Direct exposure with the on-Site sources and discharge of impacted surface water and groundwater to Hanns Inlet were considered the exposure pathways for receptors on and near the Site.

A Tier 1 risk assessment, completed as part of the DSI, concluded that exposure risk to off-Site and on-Site residents, or on-Site workers, trainees or visitors who do not undertake intrusive surface works were low and acceptable (Aurecon 2018).

However, a potentially elevated exposure risk was identified to workers who may undertake intrusive construction, or maintenance works on the Site. Exposure risk occurs through incidental ingestion of PFAS impacted soil, sediment, biosolids, surface water, and groundwater (Aurecon 2018).

Evidence was also found of exposure risk to land and aquatic biota on the Site. PFAS accumulation has been reported in fish caught within Hanns Inlet. However, as access to these waters for fishing purposes is strictly prohibited, potential exposure risk to human consumers is limited (Aurecon 2018).

More information on PFAS sources, migration mechanisms and pathways can be found in Sections 4.9 and 0 of this report.

The HMAS Cerberus N2197 Redevelopment Project commenced in April 2018. This project included the redevelopment of the FSA including an ornamental lake, located adjacent to the south of the FSA. PFAS impacted soils from this area were excavated and stockpiled along the western boundary of the former RAN SSSS training facility (Figure 4.2).

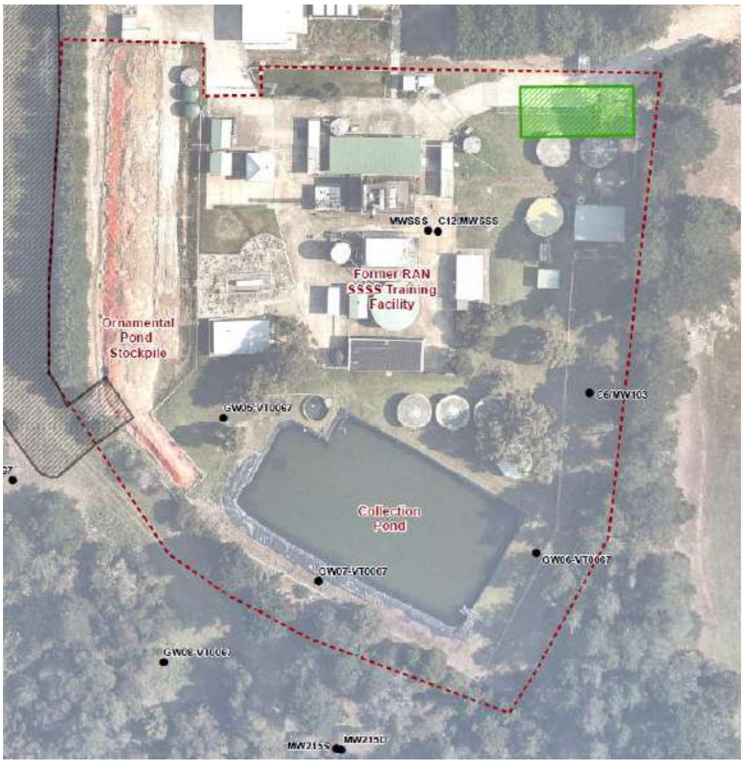


Figure 4.2 Location of soil stockpile originating from ornamental pond excavation (Golder, 2020)

Identification and management of residual PFAS impacts within the Site have been influenced by this redevelopment program rather than being driven by risk to human health and the environment or impacts to Environmental Values due to the low risk profile related to PFAS impacts at the Site and nearby vicinity.

The FTG (RAN SSSS) was identified as the main PFAS source area (largest PFAS mass) contributing to mass discharge to the environment as part of the Detailed Site Investigation (DSI) (Aurecon 2018). The redevelopment works were, in part, to facilitate the decommissioning of the FTG (and the construction of a new Fire Training facility), the modification and realignment of the Ornamental Pond (and immediate surrounds), and the construction of a new deep sewer system and associated infrastructure.

Surplus soil impacted with PFAS was generated during redevelopment works, which required suitable management. The extent of PFAS impacted soils removed from the FTG was therefore primarily driven by the extent of redevelopment works, rather than risk to Environmental Values.

Although not a primary goal of the redevelopment, removing and managing the impacted soils in the former FTG area had the potential to reduce the residual uncontrolled PFAS source mass discharge to the environment.

The following factors were considered in response to, and management of, PFAS impacts:

- The scale of the Management Area, as defined in Section 2.3 of the PMAP, is rated as “small” based on the following characteristics:
  - Small number of identified risks.
  - Contamination currently confined to isolated locations on-Base.
  - Risks of contamination to a small number of sensitive receptors.
- PFAS contamination and likely transport pathways are restricted to the terrestrial and operational boundary of the Base, except for surface waters in Hanns Inlet.
- Identified receptors at risk from PFAS contamination that require management and mitigation include:
  - On-Site ecological receptors through direct contact or uptake and/or bioaccumulation within impacted media (primarily soil and sediment) or secondary toxicity (soil moisture, surface water and groundwater).
  - On-Site construction workers primarily through incidental ingestion of PFAS-impacted media (sediment, soil, dried biosolids, surface water and groundwater) during intrusive works.
- The main PFAS source areas (in soil) are identified as the FTG (primary source), South Creek and the receiving wetlands, the FSA and Ornamental Lake.
- The primary transport mechanisms for PFAS migration are:
  - PFAS sorbed to the soil and/or sediment, through dust and direct ingestion.
  - Surface waters (including discharge through drainage channels), through dissolution.
  - Groundwater, through leaching of impacted soils and/or dissolution resulting from direct contact with impacted soils.
- PFAS concentrations in groundwater are relatively elevated within the immediate proximity of the primary, and to a lesser extent, the minor, source areas identified but are otherwise generally diffuse at low concentrations across the Site, particularly in respect of PFHxS.
- The primary point of discharge for surface waters and groundwater from the Base is Hanns Inlet.

The Site will continue to operate as a RAN training base for the foreseeable future. The SSSS facility has been redeveloped and continues to be used for this purpose. The FTG within the SSSS facility and the fire trucks at the FSA now use BIO-EX EXOPOL A 3% which is a fluorine-free firefighting foam that does not contain PFAS. This product has replaced the legacy PFAS containing AFFF.

Surrounding land uses remain unchanged and include:

- Up-hydraulic gradient: Residential, industrial (BlueScope Steel and Long Island Point petroleum storage and processing facilities), bushland, urban reserves, municipal landfill, agriculture, water treatment plant.
- Down-hydraulic gradient: Agriculture, residential, bushland, Western Port Bay, Hanns Inlet.

Technical Advisor's Opinion on available Background Information

Sufficient background information was considered to have been available from the Site investigations and risk assessment to inform the development of the PMAP and identify appropriate monitoring, management and mitigation measures based on the following considerations:

- Sufficient understanding of the historical storage, use, disposal and movement of PFAS containing AFFF was available to identify key sources and migration pathways to inform a robust and defensible sampling and analysis plan to characterise the nature and extent of PFAS impacts.
- Sufficient robust and defensible soil, sediment, surface water, groundwater and biota data were collected to characterise the nature and extent of PFAS impacts to identify source, pathway and receptor (SPR) linkages and inform an assessment of risk to Environmental Values.
- A robust and defensible Tier 1 human health and environmental risk assessment of the SPR linkages was undertaken to inform required monitoring, management and mitigation measures (if any) to reduce impacts to Environmental Values.

The available background information suggests that PFAS contamination at the Site had a very limited impact on Environmental Values and that the risk profile did not merit any urgent active mitigation measures.

The background information suggests that while there was only limited PFAS impact to Environmental Values, reduction of PFAS source mass discharge from the FTG as part of the Base redevelopment program was a prudent action in the context of the evolving understanding of risks posed by PFAS to Environmental Values. In addition, it was a proactive action to fulfill the General Environmental Duty (GED) (Environment Protection Act 2017), that states all Victorians must manage their activities to reduce the risk of harm:

- To human health and the environment
- From pollution or waste.

4.8 Site investigation activities

4.8.1 Sequence of events

Table 4.1 outlines the sequence of investigations undertaken as part of the PMAP delivery program and ongoing monitoring program (OMP). Documents detailing the investigations are also referenced. Those documents that are publicly available are hyperlinked in Section 13 References.

Table 4.1 Sequence of investigations at the Site

Date	Work summary	Reference
June 2016	**In-ground contamination site assessment.** PFAS was investigated in soils and groundwater at the RAN SSSS to inform the planning phase of the N2197 HMAS Cerberus Redevelopment Project. PFAS impacts were identified above 4.5 m depth. An estimate of 6,500 m^3 (in-situ) of PFAS impacted soil was present beneath the RAN SSSS and surrounds, in concentrations that may pose a risk to terrestrial ecology. Landfill disposal of PFAS impacted soil or disposal to an engineered containment cell constructed on Base was recommended. PFAS was detected in all groundwater samples analysed from the RAN SSSS and its surrounds. Results indicated a low risk to groundwater users surrounding the Site. However, extraction and treatment of impacted groundwater was recommended as part of site remediation works.	Golder 2016 (as summarised in Golder 2021a)
September 2016	**Environmental management preliminary sampling program.** PFAS was detected in surface water and groundwater samples collected from Site boundary locations.	GHD 2016
January 2017	**Delineation assessment at the existing RAN SSSS.** PFAS in soils were delineated in the RAN SSSS to confirm the lateral and vertical extent of the excavation. This extent was delineated by extrapolating from the impacted locations to the nearest locations or next sample depth with an acceptable contaminant concentration. A total in-situ volume of PFAS impacted soils proposed to be excavated from the RAN SSSS was 8,770 m^3.	Golder 2017a
April 2017	**Further groundwater assessment – RAN SSSS.** Three additional groundwater wells were installed down-gradient of the RAN SSSS: – One near a stormwater outlet associated with the RAN SSSS (MW121). – One nested pair further down-hydraulic gradient towards South Creek (MW122s and MW122d). The three newly installed wells and 10 existing wells located in and around the RAN SSSS were sampled. Analytical results identified: – PFAS concentrations exceeding the assessment criteria in and around the RAN SSSS and also near the stormwater outlet, south of the RAN SSSS. – A low risk to off-site receptors further down-gradient of the RAN SSSS, at the point of groundwater discharge.	Golder 2017b

Date	Work summary	Reference
April 2017 – July 2018	**Detailed Site Investigation (DSI).** A DSI was undertaken including: – A desktop investigation, which identified where and when PFAS containing AFFF was used on the Base, principally at the FTG and the Fire Station. – Field investigations, which collected data to inform a risk assessment, including: • Sampling and analysis of soil, sediment, sludge, surface water, pore water, groundwater and limited biota (vegetation and fish) from targeted locations on-site and in the surrounding area. Results of the DSI are as follows: – The primary PFAS soil source was confirmed to be located in the FTG. – PFAS impacts in soil and sediment were located at the Fire Station and nearby Ornamental Lake. – Minor soil sources were at the former STP, sports fields and sullage pit. – Surface water and groundwater were the main pathways for PFAS migration from the source areas. – PFOS was the principal component of soil impacts. – All soil impacts were below the adopted criteria for PFOS in all land use scenarios, except for intrusive workers and ecosystems. – Mass of PFAS in soil was quantified using the Kriging statistical interpolation technique which estimates values of parameters of interest in areas which have not been sampled. – Groundwater impacted by Site-derived PFAS sources is not migrating towards off-Site groundwater wells located east, west and north of the Site. – PFAS impacted groundwater from the FTG migrates towards and discharges into South Creek, located south of the FTG. – Groundwater impacted from the Fire Station and Ornamental Ponds discharges into Hanns Inlet. – PFAS impacted surface water entering the Site is minimal. – PFAS impacted surface water moves across the Site in a series of stormwater drains, discharging to tidal creeks that drain to Hanns Inlet or directly discharge into Hanns Inlet. – The PFAS mass at the Site is low and diffuse, predominantly in soil, surface water and groundwater. PFAS contamination characterised at the Site as part of the DSI posed the following risks to human health and the environment: – PFAS impacts in soils at the FTG and South Creek wetlands, surface water at the FTG lagoon, and groundwater at the FTG/South Creek pose an unacceptable risk to workers undertaking intrusive works. – This risk can be managed to a low and acceptable level by intrusive workers following the standard Defence OHS and construction environmental management plans. – There is evidence suggesting potential environmental risks (on-Site receptors) due to direct exposure and bioaccumulation/secondary contamination from PFAS contaminated soils and surface waters at the FTG, creek system and neighbouring wetlands, Fire Station /Ornamental Lake and the former STP. – There is evidence suggesting potential environmental risks (on-Site receptors) due to direct exposure and bioaccumulation/secondary contamination to PFAS impacted groundwater discharging to wetlands. – The primary driver of risk is discharge of PFAS impacted waters and groundwater to the receiving marine environment within Hanns Inlet and the potential for adverse impacts to marine biota, noting there is no adverse risk to consumers of edible fish caught within the confines of Hanns Inlet.	Aurecon 2018

Date	Work summary	Reference
October 2018	**Preparation of Defence PMAP.** The first PMAP for the Base was developed, providing a roadmap for response management by Defence of potential risks arising from PFAS contamination associated with the Base and surrounding areas, consistent with the National Environmental Management Plan (HEPA 2020). Section 11 outlines the PMAP actions, how they have been addressed and the TA's opinion on action closure.	Defence 2018
2020	**Stormwater infrastructure upgrades.** Six bioretention basins were installed and the Ornamental Lake was partially remediated with some PFAS impacted soil /sediment removed. The Category 3 soil from the Ornamental Lake was stockpiled within the footprint of the proposed Containment Cell in the FTG.	Aurecon 2021
February 2021	**Containment Cell construction.** The containment cell was constructed at the FTG.	Golder 2023c
February 2021	**Demolition of FTG.** Activities included: – Aboveground structures were demolished. – Slabs and foundations removed. – Stormwater pond water was pumped and treated through the Base water treatment system. – Concrete was crushed and stockpiled. – Plastic liners, tanks and other wastes were shredded. – Steel was segregated and disposed offsite. – 24 m^3 of tank sludge was disposed offsite. Materials placed in the containment cell included: – 2,400 m^3 of crushed concrete. – HDPE tanks and former pond liner. – 4,500 m^3 of lead contaminated soil originating from the former shooting range. – 11,000 m^3 of PFAS contaminated soil.	Golder 2023c
2021 – 2024	**Surface water and groundwater mass flux/discharge assessments.** The PFAS mass moving on and off the Site in surface water and groundwater was quantified (mass flux and mass discharge): – Surface water: refer to Section 9.2.4 for details. – Groundwater: refer to Section 9.2.5 for details.	Aurecon 2021 Aurecon 2022 Aurecon 2023 Stantec 2024
August 2023	**Preparation of an Aftercare Management Plan.** The Aftercare Management Plan details the management and monitoring procedures for the Site to assist in the management of environmental risk associated with the PFAS Containment Cell. These procedures are designed to ensure the PFAS Containment Cell is operated and maintained in accordance with the design intent. Refer to Section 8.7 for details.	Golder 2023b
October 2023	Validation of the FTG. Refer to Section 8.6 for details.	Golder 2023c

4.9 PFAS sources

A summary of these PFAS sources identified by Aurecon (2018) is summarised in Table 4.2.

Table 4.2 PFAS sources

Source description	Contaminated site record	Known & potentially affected media	Contamination mechanism	Contaminant migration processes
Primary source areas				
Fire Training Ground (FTG)	CSR_VIC_000276 (VT0067)	Concrete pavement Soil Surface waters Groundwater discharge to wetlands	As part of firefighting and training operations, AFFF containing PFAS was understood to have been used at the Site. During filling of fire extinguishers, overflow resulted in spills of fire-fighting foam, and excess foam was discharged onto fires or grassed areas and washed out, draining onto the concrete. Groundwater may be impacted through leaching of impacted soils and/or dissolution resulting in direct contact with impacted soils. An AST (3,000 L) with no bunding was used to store AFFF. Spills were expected to have occurred and resulted in discharge to the environment.	The primary migration process was surface water runoff to South Creek and surrounding wetlands and surface infiltration to groundwater (Aurecon 2018). During high rainfall events, it was noted that pond overflows occurred, and potentially contaminated water went to ground south of the ponds and flowed towards South Creek (Aurecon 2018). Historically, the overflow from the ponds discharged from drainage lines connected to the unlined ponds or overtopped the pond walls (Aurecon 2018).
Fire Station/Ornamental Lake	CSR_VIC_000447	Concrete pavement Soil Sediment and surface water in Ornamental Lake	The area is used as an operations base for fire-fighting activities. Historically, this area stored fire appliances. Site staff indicated that AFFF containing PFAS had been sprayed on the grassed area between the south edge of the Fire Station and the Ornamental Lake. AFFF use ceased in 2008. Soil and sediment were removed from the Ornamental Lake during stormwater infrastructure upgrades that took place in January 2021.	PFHxS soil impact was present in the saturated zone and is a likely pathway towards dissolved phase groundwater impacts (Aurecon 2018). Surface waters, including discharge through drainage channels. Dissolution of PFAS in soils. Carriage of PFAS absorbed to sediment.
Former STP	CSR_VIC_000140 (VT0375)	Sludge/sediment in the lagoon system Soil Collected water in lagoon system Surface water	The former on-Site STP likely received PFAS-containing AFFF residue and wastewater from the site's operational area, primarily from on-Site residences, with smaller contributions from administration, operations buildings, and the FTG. Waste management staff noted the disposal of a small quantity of AFFF near a fire hydrant at the former STP.	The former STP discharged via drains from the final southernmost lagoon to the nearby woodland, across Rifle Range Road. These drainage channels eventually discharged to Hanns Inlet (Aurecon 2018).

Source description	Contaminated site record	Known & potentially affected media	Contamination mechanism	Contaminant migration processes
Sullage Pit	CSR_VIC_000148 (VT0363)	Sediment and surface water from spoil Grass and soil in surrounding area	The Sullage Pit was used for asbestos, medical waste, and drum disposal, and later received spoil and vegetation during the Hanns Inlet channel reinstatements in 1988 and 2006. Since this spoil may contain PFAS, this area cannot be ruled out as a secondary source.	The bund wall captured the surface water, which was slowly released back into Hanns Inlet to prevent increases in turbidity.
Minor primary/secondary source areas				
Sports fields	No CSR	Grass and soil	PFAS in irrigation water, potentially associated with use of treated wastewater from the former sewer plant.	Sprinkler system used to irrigate sports field.
Bushfire area - portion of the eastern Site boundary and in the bush along the south shore of Hanns Inlet	No CSR	Grass and soil	AFFF residue may have been present in the hoses and tanks used to fight the fire.	Use of AFFF on grass and soil.
Closed Rifle Range Rd Landfill	CSR_VIC_000137 (VT0365)	Soil Surface water	The landfill's operational period suggests that used AFFF containers may have been disposed of in this area.	This area is prone to flooding caused by a combination of a king tide and strong south-south-easterly winds (Aurecon 2018).
Closed indoor & outdoor swimming pool converted to landfills	CSR_VIC_000143 (VT0366) CSR_VIC_000139 (VT0380)	Soil	A concrete-lined former swimming pool that was filled with construction debris. Although there is no evidence that the landfills received PFAS impacted waste, it was filled during a period of PFAS use, hence it was carried forward as a potential minor source.	CSR_VIC_000143 (VT0366) has a direct pipe connection to Hanns Inlet.
Storm water drains/Off-Site residential sources	No CSR	Surface water and sediment in storm water/interceptor pits and pipes	Confirmed PFAS source (Aurecon 2018). Possibly from off-Site residential sources of PFAS entering the Site via the stormwater drains.	The stormwater drainage system conveys stormwater from off-Site onto the Site at seven inflow points on the north-eastern, northern and western land boundaries (MWH/Stantec 2017).

Source description	Contaminated site record	Known & potentially affected media	Contamination mechanism	Contaminant migration processes
Underground and Aboveground Storage Tank areas	CSR_VIC_000155 (VT0191) CSR_VIC_000280 (VT0369) CSR_VIC_000279 (VT0370) CSR_VIC_000070 (VT0371) CSR_VIC_000277 (VT0372) CSR_VIC_000278 (VT0373)	Concrete and bitumen	Since the tanks were operational during the period of AFFF usage, the possibility of AFFF use in the area cannot be ruled out.	Storage and potential testing of fire extinguishers sprayed onto concrete and bitumen and subsequent runoff into stormwater drains during rain events.
Coal loading area	CSR_VIC_000138 (VT0367)	Soil	AFFF-based fire extinguishers may have been stored at the Marina near the coal loading area.	The primary PFAS migration pathway off-Site is via surface water flows. This area is hydraulically down gradient from the FTG.
Water filter wash-down area and UST (CER01) and ASTs	CSR_VIC_000069 (VT0192)	Concrete and bitumen Soil	Filters from the FTG water treatment plant may have been cleaned near Building 136, located north of the FTG within CSR_VIC_000069 (VT0192).	Likely minor impact, however, is considered to be forming an isolated groundwater plume (Aurecon, 2018).
Communications school	No CSR	Soil Surface water	AFFF containing PFAS may have been used to fill fire extinguishers.	The primary PFAS migration pathway off-Site is via surface water flows. Any AFFF spills that may have occurred during fire extinguisher filling or testing would enter soil and surface water in overland flow.
Former dry-cleaning facility	CSR_VIC_000149 (VT0368)	Soil Concrete and bitumen	Use of AFFF containing handheld fire extinguishers.	Storage and potential testing of fire extinguishers sprayed onto concrete and bitumen and subsequent runoff into storm water drains during rain events.
Powerhouse	CSR_VIC_000147 (VT0374)	Concrete and bitumen	The powerhouse was operated until 1985/1986, and potential for storage and use of AFFF exists.	The primary PFAS migration pathway off-Site is via surface water flows. This area is hydraulically down gradient from the FTG.
On-Site residential sources	No CSR	Surface water Soil	Potential non-AFFF sources include PFAS in car wax, stain-resistant coatings for carpets and textiles, car cleaning products and personal care products (USEPA, 2018).	The primary PFAS migration pathway off-Site is via surface water flows.

4.9.1 Source area mass estimates

Aurecon (2018) completed a simple mass assessment for the entire Site based on interpolated concentrations and volume mass calculations of PFAS in Site soil as defined by the extent of the analytical data set. These estimates were:

- Total PFOS in soil = approximately 60 kg in 750,000 m^3 of soil.
- Total PFOA in soil = approximately 0.06 kg in 6,000 m^3 of soil.
- Total PFHxS in soil = approximately 3 kg in 160,000 m^3 of soil.

Golder (2023c) conducted a more robust and defensible estimation of PFAS mass of the FTG source area using a numerical model based on spherical interpolation using the Leapfrog modelling software package.

Neither assessment considered the potential source mass discharge from individual sources and the contribution that discharge makes to the overall mass discharge across the Site boundary.

Identified PFAS source area mass estimates have been calculated and presented in Table 4.3.

Table 4.3 Source area mass estimates

Source ID	Source description	Adopted Mass Estimate PFOS+PFHxS (kg)	Estimated Mass Discharge (kg)	Estimated Contribution to Mass Flux (%)	TA's opinion of Confidence in Mass Estimate
FTG*	Firefighting and training operations using AFFF containing PFAS. Storage and dispensing of AFFF. Spillage and excess discharge of AFFF was common.	8.31	Unknown/Undefined by Investigation	Unknown/Undefined by Investigation	Moderate to High
Fire Station & Ornamental Lake	Operations base for fire-fighting activities and fire appliances. AFFF was historically stored here. AFFF was sprayed in the grassed area between the south edge of the Fire Station and the Ornamental Lake.	Unknown/Undefined by investigation	Unknown/Undefined by Investigation	Unknown/Undefined by Investigation	NA
Storm water drains/Off-Site residential sources	Possibly from off-Site residential sources of PFAS entering the Site via the stormwater drains.				

Notes:
Low = Lateral and Vertical Extent not Defined by Investigation Data/Interpolation Assumed or Uncorrelated
Moderate = Lateral and Vertical Extent partly Defined by Investigation Data/Interpolation partly Uncorrelated
High = Lateral and Vertical Extent mostly Defined by Investigation Data/Interpolation mostly Correlated
NA = Not applicable as no mass estimate was calculated
*Source: Golder 2023c

4.10 PFAS transport pathways – prior to cleanup

The PFAS sources described in Table 4.3 are based on the use, storage and disposal of AFFF.

AFFF is a complex mixture of water, nonfluorinated surfactants, stabilisers, solubilisers, organic solvents, and approximately 3-6% by weight PFAS. Once the AFFF is released to the environment during training, operational incidents, leakage, and disposal, the non-PFAS chemicals become subject to degradation. Most of the PFAS, except for precursor compounds, do not degrade and remain as residual contamination on the soil or infrastructure. The subsequent fate and transport of each PFAS compound from those source areas depends largely on their individual chemistry, the properties of the soil and infrastructure, and climatic conditions.

The following sections summarise the potential migration pathways for PFAS associated with soil, infrastructure, surface water, groundwater and air.

4.10.1 Infrastructure – prior to cleanup

Open drains and an engineered concrete pit and pipe network primarily comprise the stormwater network in the operational area of the Site. The stormwater drainage system conveys stormwater from off-Site onto the Site at seven inflows on the north-eastern, northern and western land boundaries (MWH Stantec 2017). Topographical gradients primarily drive PFAS from the Site then through outflows to Western Port Bay.

Six bioretention basins were constructed by Lendlease in 2020. The basins will reduce mass discharge off-Site by retaining the PFAS in sediments, within the basins. In addition, surface water sampling locations will be affected by the basins. A summary of the bioretention basins is provided in Table 4.4.

Table 4.4 Bioretention basin details (Aurecon 2021)

LendLease ID	Location	Bio-filtration area (m^2)	Discharge location	Surface water locations affected
Biobasin Device No. 2	East of Car Park 10	360	Hanns Inlet	SW007, SW008
Biobasin Device No. 5	South of Operational Area	82	Hanns Inlet	SW005*
Biobasin Device No. 9	East of re-development area	119	New channel	SW012
Biobasin Device No. 10	North of new RAN SSSS	288	Existing channel	SW013
Biobasin Device No. 11	North of Admin Building	707	Existing channel then East Creek	SW011
Biobasin Device No. 12	Near Fire Station	88	East Creek	SW009
*SW005 monitored since May 2024				

Anecdotal evidence from Base staff on 19 January 2021, noted that the Ornamental Lake was partially remediated with some PFAS impacted soil /sediment excavated prior to modification of stormwater infrastructure. The soil removed from the Ornamental Lake was stockpiled within the FTG containment cell footprint (Aurecon 2021).

Concrete is a porous material and can absorb water and AFFF applied to its surface. The PFAS from the AFFF can sorb to surfaces within the concrete and remain in the concrete until it is desorbed and mobilised through dissolution in rainwater. The rainwater forms runoff and can discharge over the sides of the concrete pad or into surface drains. Some PFAS can also seep through the concrete where the concrete is damaged and cracked. Through these pathways, PFAS can contaminate local soils or be carried further away via surface water drains.

4.10.1.1 Concentration – Concrete

Table 4.5 summarises the concentrations of PFAS species in concrete from the FTG and Ornamental Pond, based on data from Golder (2016 through 2020) as summarised in Golder 2023c and Golder 2017a.

Table 4.5 Summary of concrete data – prior to cleanup

Location	PFOS (mg/kg)	PFOA (mg/kg)	PFHxS (mg/kg)
FTG	0.51	0.013	0.12
Ornamental Pond	0.0004	<0.0002	<0.0002

Further sampling of concrete in the FTG completed by Golder in 2020, indicated levels of PFOS+PFHxS ranging from 0.0086 mg/kg to 1.471 mg/kg (Golder 2023c).

Aurecon conducted a DSI in 2018 but did not analyse any concrete samples.

Concrete samples were not obtained from other source areas on the Base.

4.10.1.2 Mass Discharge and Flux

No mass flux assessment of PFAS from concrete was conducted at the Base.

TA's opinion
Infrastructure associated with the former use of PFAS containing AFFF was considered to have been adequately characterised to allow for appropriate decommissioning and source zone identification.

4.10.2 Sediment – prior to cleanup

Incidental ingestion of PFAS contaminated sediment is considered a primary pathway for potential exposure to humans at stormwater drainage channels. The direct contact with sediment in creeks and uptake of PFAS is considered a potential pathway to on-Site aquatic flora and fauna.

4.10.2.1 Concentrations – Sediment

There are no Australian guideline values for PFAS in sediment. A summary of Aurecon's sediment data is presented in Table 4.6.

Table 4.6 PFAS concentrations in sediment (Aurecon 2018)

Source area	Max. PFOS (mg/kg)	Max. PFOA (mg/kg)	Max. PFOS+PFHxS (mg/kg)	Max. Sum of PFAS (mg/kg)	No. samples tested
Hanns Inlet	<0.001	<0.001	0.001	0.001	20
FTG	2	<0.005	2.02	2.18	1
Fire Station & Ornamental Lake	0.0051	<0.005	0.0051	<0.05	2
Former STP	2.30	0.12	2.53	3.034	11
Stormwater inflow	0.0063	<0.005	0.0063	<0.05	4
Stormwater outflow	0.053	<0.005	0.053	0.061	16
Sullage pit & other minor sources	0.018	<0.005	0.018	<0.05	4

TA's opinion
Sediments in the source areas on Site were considered to have been adequately characterised to assess risk to environmental values. Refer to Table 4.8 for a summary of Environmental Values.

4.10.3 Soil – prior to cleanup

Incidental ingestion of PFAS contaminated soil is considered a primary pathway for potential exposure to humans. The direct contact with surface soil/vegetation and uptake of PFAS is considered a potential pathway to on-Site terrestrial flora and fauna. Direct contact (exposure) or uptake applies specifically to organisms that live within, or are closely associated with, the soil, such as earthworms and plants.

4.10.3.1 Concentrations – Soil

Aurecon (2018) analysed soil samples across the on-Site source areas. Golder (2017a) also analysed soil samples from the FTG for PFOS+PFHxS. A summary of concentration results is presented in Table 4.7.

Table 4.7 PFAS concentrations in soil (Aurecon 2018 and Golder 2017a) – prior to cleanup

Source area	Data source	Max. PFOS (mg/kg)	Max. PFOA (mg/kg)	Max. PFOS+PFHxS (mg/kg)	Max. Sum of PFAS (mg/kg)	No. samples tested	Exceeding applicable criteria
FTG & South Creek wetlands	Aurecon 2018	12.0	0.030	12.1	12.3	27	Yes: EGV1 direct exposure (public open space) – PFOS 1 mg/kg EGV3 indirect exposure (industrial/commercial) – PFOS 0.14 mg/kg HH3 Public open space – PFOS+PFHxS 1 mg/kg HH5 Intrusive / maintenance workers PFOS+PFHxS 1 mg/kg
	Golder 2017a	2.5	0.0695	2.61	2.66	204	Yes: EGV1 direct exposure (public open space) – PFOS 1 mg/kg EGV3 indirect exposure (industrial/commercial) – PFOS 0.14 mg/kg HH3 Public open space – PFOS+PFHxS 1 mg/kg HH5 Intrusive / maintenance workers PFOS+PFHxS 1 mg/kg
Fire Station & Ornamental Lake	Aurecon 2018	1.10	0.003	1.12	1.15	18	Yes: EGV1 direct exposure (public open space) – PFOS 1 mg/kg EGV3 indirect exposure (industrial/commercial) – PFOS 0.14 mg/kg HH3 Public open space – PFOS+PFHxS 1 mg/kg HH5 Intrusive / maintenance workers PFOS+PFHxS 1 mg/kg
Former STP	Aurecon 2018	0.16	0.008	0.171	0.195	13	Yes: EGV3 indirect exposure (industrial/commercial) – PFOS 0.14 mg/kg
Sullage pit, sports field, minor sources, site land boundaries	Aurecon 2018	0.039	<0.001	0.039	0.22	74	Yes: EGV2 indirect exposure (residential) – PFOS 0.01 mg/kg

Notes:

mg/kg – milligrams per kilogram

Minor primary and secondary sources: sports field, bushfire area, closed landfills, stormwater drains/off-Site residential sources, storage tank areas, coal loading area, water filter wash-down area and UST and ASTs, Communications School, former dry-cleaning facility, powerhouse, on-Site residential sources.

4.10.3.2 Mass flux

PFAS modelling at the FTG, conducted in 2021 before cleanup activities, estimated that the top 0.5 m of soil contained approximately 3.35 kg of PFOS+PFHxS (Golder 2023c). PFAS mass flux from soil to other media was not assessed prior to cleanup activities.

> **TA's opinion**
> Soils in the source areas on Site were considered to have been adequately characterised to inform and assess risk to Environmental Values. Refer to Table 4.8 for a summary of Environmental Values.

4.10.3.3 Environmental Values of land

An assessment of Environmental Values of land is provided in Table 4.8. Sediment, although it forms new landforms, is typically not considered as land but rather of the aquatic system. Therefore, in this instance, the Environmental Values are applicable to soil only.

EVs are assessed by reviewing relevancy and if an EV is precluded. A soil EV is relevant based on current and potential use based on permitted uses as specified by Jurisdictional regulations (eg planning authority). An EV that is precluded means a contaminant exceeds criterion for that use, irrespective of whether that use is allowed or relevant.

Table 4.8 Land (soils) Environmental Values assessment – prior to cleanup

Land (soil) Environmental Value	Relevant?	Precluded on-Site?	Precluded off-Site?	TA's opinion
Maintenance of ecosystems (terrestrial)	Yes	**Yes** PFAS detections across the Site above Tier 1 risk assessment criteria.	No No PFAS detections above the relevant off-site Environmental Values protection criteria along the Site boundary.	Assessing the risk of PFAS in soil to on-Site ecological receptors is warranted.
Human health – residential (and childcare attendees)	No Pathway from sources is incomplete as no access to contaminated soil.	**Yes** PFAS detections across the Site above Tier 1 risk assessment criteria.	No Applicable PFAS concentrations were below the Tier 1 risk assessment criteria with respect to protection of the off-site Environmental Values.	No further assessment warranted.
Human health – Open spaces/playing fields	Yes	**Yes** PFAS detections across the Site above Tier 1 risk assessment criteria.	No PFAS concentrations were below the Tier 1 risk assessment criteria for site boundary locations.	Assessing the risk of PFAS in soil to on-Site open spaces and playing fields is warranted. The use of playing fields is best represented by trainees engaged in outdoor exercises.
Human health – Commercial/Industrial	Yes	No PFAS concentrations were below the Tier 1 risk assessment criteria.	No PFAS concentrations were below the Tier 1 risk assessment criteria for site boundary locations.	No further assessment warranted.
Human health – Intrusive/Maintenance Workers	Yes	**Yes** PFAS detections across the Site above Tier 1 risk assessment criteria.	No PFAS concentrations were below the Tier 1 risk assessment criteria for site boundary locations.	Assessing the risk of PFAS in soil to on-Site intrusive/maintenance workers is warranted.
Buildings and structures	No	NA PFAS is not known to impact the environmental value of Buildings and Structures.	NA PFAS is not known to impact the environmental value of Buildings and Structures.	No further assessment warranted.
Aesthetics	No	No No evidence of visual impact by PFAS (such as foams).	No No evidence of visual impact by PFAS (such as foams).	No further assessment warranted.
Production of food, flora and fibre	No on-Site (no food) /Yes off-Site.	**Yes** PFAS detections across the Site above Tier 1 risk assessment criteria.	No Applicable PFAS concentrations were below the Tier 1 risk assessment criteria with respect to protection of the off-site Environmental Values.	No further assessment warranted.

4.10.4 Surface water – prior to cleanup

Pathways for PFAS contaminated surface water for human receptors may be through incidental ingestion during non-potable use, such as during swimming associated with survival training in Hanns Inlet, or during the conduct of site maintenance works. Other pathways include deliberate ingestion during potable uses or dermal contact (minor pathway).

Direct contact with surface water and groundwater interaction zones, along with PFAS uptake, is a potential pathway affecting aquatic flora and fauna both on and off-Site.

Surface water is also a relevant exposure pathway linking the FTG with the South Creek wetlands, and ultimately Hanns Inlet.

4.10.4.1 Concentrations

PFAS concentrations in surface water were assessed by Aurecon (2018) and through the OMP for a period beginning in 2017 to 2020 (prior to cleanup activities). This data is summarised in Table 4.9.

Table 4.9 PFAS concentrations in surface water (Aurecon 2018) – prior to cleanup (2017 – 2020)

Source area (location IDs)	Max. PFOS (µg/L)	Max. PFOA (µg/L)	Max. PFOS+PFHxS (µg/L)	Max. Sum of PFAS (µg/L)	No. samples tested	Exceeding applicable criteria
Hanns Inlet (SW004, SW077)	0.0089	<0.001	0.011	0.011	43	Yes: Ecological 99% protection PFOS – 0.00023 µg/L
FTG & South Creek wetlands (SW027, SW029)	33	0.78	36.9	55.2	4	Yes: Ecological 95% protection PFOS – 0.13 µg/L Ecological 99% protection PFOS – 0.00023 µg/L Human health recreational PFOS+PFHxS – 0.7 µg/L)
Fire Station & Ornamental Lake (SW018, SW019, SW020)	0.45	0.1	1.85	3.82	2	Yes: Ecological 95% protection PFOS – 0.13 µg/L Ecological 99% protection PFOS – 0.00023 µg/L Human health recreational PFOS+PFHxS – 0.7 µg/L)
Former STP (SW014, SW015, SW016, SW017, SW023, SW079)	5.4	1.3	10.5	23.6	4	Yes: Ecological 95% protection PFOS – 0.13 µg/L Ecological 99% protection PFOS – 0.00023 µg/L Human health recreational PFOS+PFHxS – 0.7 µg/L)
Stormwater inflow (SW021, SW022, SW024)	0.05	<0.01	0.130	0.15	4	Yes: Ecological 99% protection PFOS – 0.00023 µg/L
Stormwater outflow (SW001 – SW004, SW006 – SW013, SW029, SW030)	0.57	0.034	0.79	0.97	17	Yes: Ecological 95% protection PFOS – 0.13 µg/L Ecological 99% protection PFOS – 0.00023 µg/L Human health recreational PFOS+PFHxS – 0.7 µg/L)
Sullage pit & minor primary and secondary sources (SW025, SW026)	0.32	0.24	0.34	0.38	5	Yes: Ecological 95% protection PFOS – 0.13 µg/L Ecological 99% protection PFOS – 0.00023 µg/L

Notes: µg/L: micrograms per litre

Minor primary and secondary sources: sports field, bushfire area, closed landfills, stormwater drains/off-Site residential sources, storage tank areas, coal loading area, water filter wash-down area and UST and ASTs, Communications School, former dry-cleaning facility, powerhouse, on-Site residential sources.

Surface water samples were collected and analysed from Hanns Inlet, near Western Port Bay at locations deemed unlikely to be impacted by on-Site PFAS contamination (i.e., background concentrations) (Aurecon 2018). No PFAS compounds were detected at these background locations. Therefore, there are unlikely to be any sources of PFAS contributing to the mass discharge volume onto the Site of measurable concentration (i.e. above LOR).

4.10.4.2 Mass flux

Aurecon (2018) provided an estimate of mass flux via surface water.

Surface water samples were obtained from two inflow locations to assess mass flux of PFAS entering the Site and 17 outflow locations, to assess mass flux leaving the Site. The assessment was conducted to assess the relative contribution from each sampling location in response to rain events. The data was only representative of a single time period (i.e. August 2018) and values are likely to vary over the course of a year.

Th mass flux assessment results indicated the total mass discharge into the tidal creeks or directly into Hanns Inlet was approximately 0.85 g/day or 311 g/year PFOS+PFHxS. The inflow flux was in the order of 0.12 g/day or 44 g/year PFOS+PFHxS.

Based on the data presented, the inflow to the Site was approximately seven times lower than the flux from the Site. This confirms that the Site is a source of PFAS mass loading and contributor to the mass flux into the receiving environment.

The assessment found that the main contributions were from outlets adjacent to the closed outdoor swimming pool landfill located south of the Communications School.

Investigations (Aurecon 2018) identified a number of Environmental Values (i.e. previously referred to as beneficial uses) for segments of the environment relevant to the Site that may be precluded due to risks posed by PFAS contamination (both on-Site and off-Site). Environmental Values were evaluated in regard to these risks (Aurecon 2018). The TA has also reviewed Environmental Values of surface water, and a synopsis is provided in Table 4.10.

TA's opinion

Surface water moving across the Site and at the discharge points into the off-site environment was considered to have been adequately characterised to assess risk to Environmental Values.

4.10.4.3 Environmental Values of surface water

An assessment of Environmental Values of surface water is provided in Table 4.10. Environmental Values are assessed by reviewing relevancy and if an Environmental Value is precluded. A water Environmental Value is relevant based on current and potential use based on water quality as specified by Jurisdictional regulations. An Environmental Value that is precluded means a contaminant exceeds criterion for that use, irrespective of whether that use is allowed or relevant.

Table 4.10 Surface water Environmental Values assessment

Surface water environmental value	Relevant	Precluded on-Site	Precluded off-Site	TA's opinion
Water dependent ecosystems and species (Largely unmodified/slightly to moderately modified/highly modified)	Yes	**Yes** Reported PFAS concentrations were above the Tier 1 risk assessment criteria.	**Yes** Reported PFAS concentrations were above the relevant Tier 1 risk assessment criteria outside the mouth of Hanns Inlet.	Assessing the risk of PFAS in surface water to on-Site ecological receptors is warranted.
Human consumption after appropriate treatment (reduction of TDS to 500 mg/L)	On-Site: No (not used for human consumption). Off-Site: Yes	**Yes** Reported PFAS concentrations were above the Tier 1 risk assessment criteria.	No Off-site surface waters are located hydraulically upgradient.	No further assessment warranted.
Agriculture and irrigation	On-Site: No (not used for irrigation). Off-Site: Yes	**Yes** Reported PFAS concentrations were above the Tier 1 risk assessment criteria.	No Off-site surface waters are located hydraulically upgradient.	No further assessment warranted.
Human consumption of aquatic foods	No Unlikely to occur due to restrictions on use of Hanns Inlet and Western Port Bay and on-Site for this purpose	**Yes** Reported PFAS concentrations were above the Tier 1 risk assessment criteria.	No Reported PFAS concentrations were above the relevant Tier 1 risk assessment criteria outside the mouth of Hanns Inlet. However, unlikely due to tidal flushing and connection with Western Port Bay.	Assessing the risk of PFAS in surface water to on-Site humans consuming aquatic foods is not warranted.
Aquaculture	No Aquaculture unlikely to occur due to restrictions on use of Hanns Inlet and Western Port Bay and on-Site.	**Yes** Reported PFAS concentrations were above the Tier 1 risk assessment criteria.	No Reported PFAS concentrations were above the relevant Tier 1 risk assessment criteria outside the mouth of Hanns Inlet. However, unlikely due to tidal flushing and connection with Western Port Bay.	Assessing the risk of PFAS in surface water to production of aquaculture. is not warranted.
Industrial and commercial	No	NA	NA	PFAS in surface water are not known to impact the

Surface water environmental value	Relevant	Precluded on-Site	Precluded off-Site	TA’s opinion
				Environmental Value of Industry and commercial. No further assessment warranted.
Water-based recreation (primary contact*)	No due to access restrictions	**Yes** Reported PFAS concentrations were above the Tier 1 risk assessment criteria.	No Reported PFAS concentrations were below the Tier 1 risk assessment criteria outside the mouth of Hanns Inlet, which is tidally flushed, and connected to Western Port Bay.	Assessing the risk of PFAS in surface water to on-Site humans engaging in water-based recreation is not warranted.
Water-based recreation (secondary contact*)	No, due to access restrictions Yes, for those involved in drain maintenance	**Yes** For the drainage and discharge point. Reported PFAS concentrations were above the Tier 1 risk assessment criteria **No** For Hanns Inlet. Reported PFAS concentrations were below the Tier 1 risk assessment criteria.	No Reported PFAS concentrations were below the Tier 1 risk assessment criteria outside the mouth of Hanns Inlet, which is tidally flushed, and connected to Western Port Bay.	No further assessment warranted due to restrictions on access to surface waters on-Site for this purpose. Under the Victorian Government Environment Reference Standard (Victorian Government 2021) definition, this includes water contact without ingestion and can apply to workers involved in maintenance of drains. Therefore, any personnel involved in drain maintenance must work under applicable OHS protocols.
Water-based recreation (aesthetic enjoyment)	Yes	No No foaming caused by PFAS was observed during investigations.	No No foaming caused by PFAS was observed during investigations.	No further assessment warranted.
Tradition Owner cultural values	No, for surface water in man-made drains on-Site Yes, for point of discharge in Hanns Inlet	**Yes** For the drainage and discharge point. Reported PFAS concentrations were above the Tier 1 risk assessment criteria **No** For Hanns Inlet. Reported PFAS concentrations were below the Tier 1 risk assessment criteria.	No Reported PFAS concentrations were below the Tier 1 risk assessment criteria outside the mouth of Hanns Inlet, which is tidally flushed, and connected to Western Port Bay.	Assessing the risk of PFAS in surface water to on-Site humans practising Traditional Owner cultural values through water-based recreation is not warranted. It only applies to Hanns Inlet itself, which reported PFAS concentrations below the Tier 1 risk assessment criteria.

Surface water environmental value	Relevant	Precluded on-Site	Precluded off-Site	TA's opinion
Navigation and shipping	No	NA	NA	PFAS in surface water are not known to impact the Environmental Value of Navigation and shipping. No further assessment warranted.
*Primary contact is where a human has direct contact with contaminated water, be fully immersed and ingest it. *Secondary contact is where a human has direct contact with contaminated water but is unlikely to ingest it.				

4.10.5 Groundwater – prior to cleanup

Pathways for PFAS contaminated groundwater may be through incidental ingestion during non-potable use. This may be during the conduct of site maintenance and/or intrusive construction works.

Direct contact with groundwater and uptake of PFAS is also a potential exposure pathway for on-Site terrestrial flora and fauna. The extent of this pathway is species dependent (e.g. depth of plant roots, feeding habits).

Risk to stygofauna was not considered, as such fauna is not likely to be present in the groundwater system at the Site. Risks to aquatic ecosystems were considered as part of the surface water assessment as exposure would occur in that setting.

Groundwater is a complete exposure pathway linking the FTG with the South Creek wetlands, and ultimately Hanns Inlet.

4.10.5.1 Concentrations

Aurecon (2018) reported that nine out of 10 groundwater monitoring wells at the Site land boundaries recorded non-detects for all PFAS compounds. One exception was MW207, located near the Bushfire area. Therefore, it is assumed that background PFAS concentrations are below respective LORs (i.e. 0.001 – 0.005 µg/L). Table 4.11 provides a summary of PFAS concentrations reported in groundwater sampled from the Site source areas as part of the Further Groundwater Assessment (Golder 2017b) and DSI (Aurecon 2018). Table 4.12 provides a summary of PFAS concentrations reported in groundwater as part of the OMP.

Table 4.11 PFAS concentrations in groundwater (Golder 2017b and Aurecon 2018) – prior to cleanup

Source area	Data source	Max. PFOS (µg/L)	Max. PFOA (µg/L)	Max. PFOS+PFHxS (µg/L)	Max. Sum of PFAS (µg/L)	No. samples tested	Exceeding applicable criteria
FTG & South Creek wetlands	Golder 2017b	86.6	39	657	-	10	Yes: Ecological 95% protection PFOS – 0.13 µg/L Ecological 99% protection PFOS – 0.00023 µg/L Ecological 99% protection PFOA – 19 µg/L Human health drinking water PFOA – 0.56 µg/L Human health recreational PFOS+PFHxS – 0.7 µg/L) Human health drinking water PFOS+PFHxS – 0.07 µg/L)
	Aurecon 2018	382	63	598	780	34	Yes: Ecological 95% protection PFOS – 0.13 µg/L Ecological 99% protection PFOS – 0.00023 µg/L Ecological 99% protection PFOA – 19 µg/L Human health drinking water PFOA – 0.56 µg/L Human health recreational PFOS+PFHxS – 0.7 µg/L) Human health drinking water PFOS+PFHxS – 0.07 µg/L)
Fire Station & Ornamental Lake	Aurecon 2018	0.025	0.038	0.682	1.37	4	Yes: Ecological 99% protection PFOS – 0.00023 µg/L
Former STP	Aurecon 2018	0.067	0.020	0.267	1.683	10	Yes: Ecological 99% protection PFOS – 0.00023 µg/L
Sullage pit	Aurecon 2018	3.30	0.065	4.14	4.61	2	Yes: Ecological 95% protection PFOS – 0.13 µg/L Ecological 99% protection PFOS – 0.00023 µg/L Human health recreational PFOS+PFHxS – 0.7 µg/L)
Minor primary and secondary sources	Aurecon 2018	0.7	0.24	3.72	4.42	86	Yes: Ecological 95% protection PFOS – 0.13 µg/L Ecological 99% protection PFOS – 0.00023 µg/L Human health recreational PFOS+PFHxS – 0.7 µg/L)

Notes:

µg/L: micrograms per litre

Minor primary and secondary sources: sports field, bushfire area, closed landfills, stormwater drains/off-Site residential sources, storage tank areas, coal loading area, water filter wash-down area and UST and ASTs, Communications School, former dry-cleaning facility, powerhouse, on-Site residential sources.

Table 4.12 PFAS concentrations in groundwater (OMP dataset) – prior to cleanup (2017 – 2020)

Source area	Monitoring locations	Ave. PFOS (µg/L) (data range)	Ave. PFOA (µg/L) (data range)	Ave. PFOS+PFHxS (µg/L) (data range)	Ave. Sum of PFAS (µg/L) (data range)	No. samples tested	Exceeding applicable criteria
Criteria	PFAS NEMP 2020 Drinking Water	NA	0.56	0.07	NA		
	PFAS NEMP 2020 Recreational Water	NA	10	2	NA		
Upgradient of Site operational area	MW204, MW206, MW207, MW210	0.0018 (<0.0002-0.02)	0.0027 (<0.0002-0.019)	0.003 (<0.0002-0.02)	0.0089 (<0.0002-0.06)	26	No
FTG & South Creek wetlands	MW017, MW018, MW063, MW074, MW075, MW121, MW122D, MW122S, MW212, MW213, MW214S, MW215D, MW215S, MW067	6.96 (<0.0001-47)	0.42 (<0.0002-3.64)	16.17 (<0.0002-79.80)	22.20 (<0.0002-123)	59	Yes
Fire Station & Ornamental Lake	MW110	0.0223 (<0.0001-0.05)	0.0234 (<0.0002-0.04)	0.4163 (<0.0002-0.682)	0.9789 (<0.0002-1.88)	16	Yes
Former STP	MW217D, MW218	0.0082 (<0.0001-0.04)	0.0003 (<0.0002-0.002)	0.0113 (<0.0002-0.08)	0.0140 (<0.0002-0.08)	38	Yes
Sullage pit	MW025	2.503 (0.76-4.32)	0.0555 (0.05-0.065)	3.245 (1.54-5.07)	3.598 (1.73-5.52)	10	Yes
Minor primary and secondary sources	MW019, MW041 MW064, MW028, MW029, MW030, MW033, MW060, MW034, MW036, MW102, MW068, MW109, MW069, MW070, MW071, MW043, MW061, MW062, MW046, MW047, MW051, MW054	0.1627 (<0.0001-3.03)	0.0191 (<0.0002-0.19)	0.4599 (<0.0002-7.19)	0.6230 (<0.0002-8.46)	262	Yes

Notes:

µg/L: micrograms per litre

Minor primary and secondary sources: sports field, bushfire area, closed landfills, stormwater drains/off-Site residential sources, storage tank areas, coal loading area, water filter wash-down area and UST and ASTs, Communications School, former dry-cleaning facility, powerhouse, on-Site residential sources, closed rifle range.

NA – not criteria available

4.10.5.2 Mass flux

No mass flux assessment was completed for groundwater prior to soil cleanup activities.

TA's opinion

Groundwater on-Site was considered to have been adequately characterised to assess risk to Environmental Values. Please note, groundwater discharges to Hanns Inlet, which forms part of the Site. Refer to Table 4.13 for a summary of Environmental Values of groundwater.

4.10.5.3 Environmental Values of groundwater

An assessment of Environmental Values of groundwater is provided in Table 4.13. EVs are assessed by reviewing relevancy and if an EV is precluded. A groundwater EV is relevant based on current and potential use based on water quality as specified by Jurisdictional regulations. An EV that is precluded means a contaminant exceeds criterion for that use, irrespective of whether that use is allowed or relevant.

Table 4.13 Groundwater Environmental Values assessment

Groundwater Environmental Value	Relevant	Precluded on-Site	Precluded off-Site	TA's opinion
Water dependent ecosystems and species	Yes	No Potentially complete pathway in consideration of groundwater supporting water dependent ecosystems and species at the point of discharge, i.e. Hanns Inlet. However, groundwater is not considered to be utilised by ecological receptors on-Site.	No Incomplete pathway. Point of discharge is considered to be on-Site, into Hanns Inlet. Mixing of sea water between Hanns Inlet and Western Port Bay would reduce PFAS concentrations to a low and acceptable risk level.	The Tier 1 risk assessment considered that risks with respect to this Environmental Value at the point of discharge are low and acceptable.
Potable water supply (desirable and acceptable)	On-Site: No (not used for potable water supply). Off-Site: Yes	No TDS >1,200 mg/L, therefore not suitable for potable use.	No PFAS not detected in off-site wells. Potable water wells are located hydraulically up-gradient of the Site.	No further assessment warranted.
Potable mineral water supply	No	NA	NA	The Site is not in a mineral water zone. No further assessment warranted.
Agriculture and irrigation (irrigation)	No (TDS > 3,100 mg/L)	Yes PFAS concentrations above adopted Tier 1 risk assessment criteria.	No PFAS not detected in off-site wells.	TDS generally >3,100 mg/L due to tidal influences. Therefore, unlikely to be suitable for agricultural and irrigation purposes. The Tier 1 risk assessment considered that risks with respect to this Environmental Value are low and acceptable.
Agriculture and irrigation (stock watering)	On-Site: No (not used for stock water supply). Off-Site: Yes	Yes PFAS concentrations above adopted Tier 1 risk assessment criteria.	No PFAS not detected in off-site wells.	The Tier 1 risk assessment considered that risks with respect to this Environmental Value are low and acceptable.

Groundwater Environmental Value	Relevant	Precluded on-Site	Precluded off-Site	TA’s opinion
Industrial and commercial use	Yes	Yes PFAS concentrations above adopted Tier 1 risk assessment criteria (incidental ingestion).	No PFAS not detected in off-site wells.	The Tier 1 risk assessment considered that risks with respect to this Environmental Value are low and acceptable.
Water-based recreation (primary contact recreation) including intrusive workers	Yes	Yes PFAS concentrations above adopted Tier 1 risk assessment criteria (incidental ingestion).	No PFAS not detected in off-site wells.	Assessing the risk of PFAS in groundwater to on-Site humans in this scenario is warranted. Managed through Defence OHS and CMF plans.
Traditional Owner cultural values	Yes	No PFAS concentrations in water at the point of discharge do not exceed Tier 1 risk assessment criteria.	No PFAS concentrations in water at the point of discharge do not exceed Tier 1 risk assessment criteria.	This is considered at the point of discharge, i.e. Hanns Inlet. No further assessment warranted.
Buildings and structures	No	NA	NA	PFAS do not impact the Environmental Value of Buildings and structures. No further assessment warranted.
Geothermal properties	No	NA	NA	The Site is not in a geothermal zone. No further assessment warranted.

4.10.6 Air – prior to cleanup

Some PFAS compounds have the potential to form a vapour phase and be transported in that phase. PFAS are typically manufactured and sold in a solid salt form, bonded to elements and compounds such as potassium, ammonia. In this solid non-ionic form, Perfluoroalkyl acids (PFAAs) have appreciable volatility. Other compounds such as fluorotelomer alcohols (FTOHs) are also somewhat volatile, due to the alcohol moiety, and may partition to air in vapour phase. However, PFAAs dissolved in water typically form ions in water and these ionic forms are not volatile.

In AFFF, the PFAS are dissolved in the concentrate and are present in an ionic dissolved form, and therefore largely non-volatile. However, when AFFF is applied to a hot asphalt surface, say an airport runway, the water in the AFFF can evaporate leaving behind a higher proportion of organic solvents. The solvents can dissolve PFAS and entrain them in a vapour phase form (Bastow et al. 2022). Such a scenario is likely to be related to training or fire incidents and therefore, short-lived. These types of PFAS vapour phase emissions are generally temporary.

PFAS can also be transported through mobilisation of airborne contaminated soils (dust) which is more likely to occur during dry, windy periods. Inhalation of dust and airborne particulates containing PFAS is considered a minor pathway.

4.10.6.1 Concentration

No assessment of PFAS in air has been conducted. The PFAS transport mechanisms described above are not considered an ongoing potential transport pathway to receptors as any volatile forms would have been lost soon after release and the majority of the PFAS in AFFF would have been originally dissolved ionic form. Therefore, no on-Site volatile PFAS source was considered to be present and could not pose a potential vapour risk.

4.10.6.2 Mass Flux

No assessment of PFAS mass flux in air has been conducted and is not considered necessary.

TA's opinion
Due to the nature of volatile PFAS compounds, their presence on the Site was considered unlikely and therefore risks were considered low and acceptable and no impacts to Environmental Values of air in the context of the current site status. No further assessment of this transport pathway was considered to be warranted.

4.11 Receptors – prior to cleanup

Hanns Inlet may receive PFAS from primary sources via groundwater and surface water flows. Sediments and pore water in the Inlet could also become secondary sources. Aurecon's review suggests that the surface water, sediment, and pore water in Hanns Inlet are not well-characterised enough to confirm a complete SPR linkage. Fishing is prohibited in Hanns Inlet and Naval waters, which are patrolled by water police. Territorial species like flathead and whiting are likely to stay within the Inlet, while migratory species such as snapper may leave and be consumed by other fauna or humans.

On-Site and off-Site receptors are outlined in Table 4.14 and Table 4.15. SPR linkages have been considered as follows:

- Complete (no qualification, receptors and pathway known).
- Incomplete (no qualification, no receptor and/or no pathway to source).
- Potentially complete (qualification where likelihood is likely, possible or unlikely).

Table 4.14 Human receptor assessment

Human receptor	Complete SPR linkage	Level of risk	TA's opinion
On-Site			
Base workers and trainees	Yes	Potentially Elevated	Management or mitigation recommended.
Intrusive construction workers	Yes	Potentially Elevated	Management or mitigation recommended.
Site visitors	Yes (Likely)	Low and acceptable	Does not require further consideration. While site visitors are possible, the frequency of visits and site activity is likely to result in low level exposure to PFAS.
Childcare attendees	No	Low and acceptable	Does not require further consideration. Pathway from sources is incomplete as no access to contaminated soil or water.
Residents	No	Low and acceptable	Does not require further consideration. Pathway from sources is incomplete as no access to contaminated soil or water.
Off-Site			
Commercial producers of agricultural products	No	Not assessed	Pathway from sources is incomplete due to flow direction of surface water and groundwater. Does not require further consideration.
Commercial producers of aquaculture products	No	Low and acceptable	No fishing or aquaculture is permitted in Hanns Inlet and Naval Water. Does not require further consideration.
Western Port Bay fish consumers	Yes (Unlikely)	Low and acceptable	Does not require further consideration.
Wildlife or game consumers	No	Not assessed	No indications of wildlife or game consumption in the area. Does not require further consideration.

Table 4.15 Ecological receptor assessment

Ecological receptor	Complete SPR linkage	Level of risk	TA's opinion
On-Site terrestrial flora			
Grass, trees and other vegetation	Yes (Likely)	Low and acceptable	Does not require further consideration.
On-Site terrestrial fauna			
Mammals, including rabbits, kangaroos and possums	Yes (Likely)	Low and acceptable	Does not require further consideration.
Birds, migratory and local	Yes (Likely)	Low and acceptable	Does not require further consideration.
Reptiles and insects	Yes (Likely)	Low and acceptable	Does not require further consideration.
Grass, trees and other vegetation	Yes (Likely)	Low and acceptable	Does not require further consideration.
Semi-aquatic biota, including crabs and worms	Yes (Likely)	Low and acceptable	Does not require further consideration.
On-Site aquatic fauna			
Fish, including flathead, whiting, mullet, Australian salmon, toad fish and trevally	Yes (Likely)	Low and acceptable	Does not require further consideration.
Fiddler rays and gummy sharks	Yes (Likely)	Low and acceptable	Does not require further consideration.
Pipis, oysters and crustaceans	Yes (Likely)	Low and acceptable	Does not require further consideration.

Ecological receptor	Complete SPR linkage	Level of risk	TA’s opinion
Benthic detritivores	Yes (Likely)	Low and acceptable	Does not require further consideration.
Off-Site terrestrial flora			
Grass, trees and other vegetation	No	Low and acceptable	Does not require further consideration. Pathway is incomplete due to the groundwater flow direction causing PFAS migration away from these receptors.
Off-Site terrestrial fauna			
Mammals, including horses, cows, rabbits and possums	No	Not assessed	Does not require further consideration. Pathway is incomplete due to the groundwater flow direction causing PFAS migration away from these receptors.
Birds, migratory and local	Yes (Possible)	Low and acceptable	Does not require further consideration. Off-Site biota that come onto the Site could potentially be exposed to on-Site sources of PFAS, such as in the wetlands straddling South Creek.
Off-Site aquatic fauna			
Fish, including flathead, whiting, mullet, Australian salmon, toad fish and trevally	Yes (Unlikely)	Low and acceptable	Does not require further consideration. Pathway is unlikely to be complete due to flushing properties of Hanns Inlet.
Fiddler rays and gummy sharks	Yes (Unlikely)	Low and acceptable	Does not require further consideration. Pathway is unlikely to be complete due to flushing properties of Hanns Inlet.
Pipis, oysters and crustaceans	Yes (Unlikely)	Low and acceptable	Does not require further consideration. Pathway is unlikely to be complete due to flushing properties of Hanns Inlet.
Benthic detritivores	Yes (Unlikely)	Low and acceptable	Does not require further consideration. Pathway is unlikely to be complete due to flushing properties of Hanns Inlet.

4.12 Risks to Environmental Values – prior to cleanup

Based on the synopsis of risk to Environmental Values and receptors as outlined in Sections 0 and 4.11, there is a potentially elevated risk to the Environmental Value of Human Health Intrusive/Maintenance workers (i.e. Base workers and trainees and intrusive construction workers) due to the reported PFAS concentrations in soil within the following source areas:

– FTG & South Creek wetlands.
– Fire Station & Ornamental Lake.

The risk posed by the PFAS concentrations in soils in this exposure scenario are considered potentially elevated but not unacceptable. The decision to undertake PFAS source mass discharge reduction within the FTG was therefore an opportunistic one, rather than a risk mitigation measure.

TA’s opinion on Site characterisation and risk assessment prior to cleanup

The Site’s geomorphological setting was considered to have been adequately characterised to inform a Tier 1 risk assessment. However, insufficient characterisation of some aspects of PFAS mass resulted in some data gaps. These data gaps were specifically considered to include:

– The mass of PFAS within each source area was not adequately characterised. While an estimate was made of the total PFAS mass present on the Site, this estimate was not attributed to the individual sources identified.
– The mass discharge from each source area was not characterised, which limits the ability to identify the relative contribution of each source to the overall mass discharge that leaves the Site.
– No assessment of mass flux from the source areas and Base was conducted before implementing management and mitigation measures, including capping and containing PFAS-impacted soils in the FTG. As such, no baseline information to assess the effectiveness of the management and mitigation measure on mass flux is available.

The assessment of risk to Environmental Values was considered to have been adequately undertaken through use of a robust and defensible Tier 1 risk assessment. The Tier 1 risk assessment demonstrated that the data gaps identified did not materially affect the ability to assess implementation of appropriate and effective management and mitigation measures for PFAS impacts, based on the following lines of evidence:

– Risks to all on and off-Site receptors with chronic and long-term exposure were found to be low and acceptable.
– Risks to on-Site receptors with short-term, direct exposure (primarily those in direct contact with the soils, surface water and groundwater (e.g. Base worker, Defence trainees and construction/maintenance workers) are potentially elevated. However, these risks can be readily managed and mitigated by simple and easily implementable occupational health and safety measures.

Based on these considerations, the TA concludes that the Site conditions were sufficiently characterised before implementing management and mitigation measures, allowing for an effective assessment of their impact on PFAS-relevant Environmental Values.

5. Site cleanup decision process

PFAS investigations completed at the Site concluded that the risk to Environmental Values on-Site and off-Site is generally low. Elevated risks were limited to a small number of on-Site receptors that can be readily managed through implementation of simple and effective management measures. In light of this, Site cleanup was completed opportunistic as part of the redevelopment works and to support Defence's responsibility of the GED, rather than to manage and mitigate elevated risk and restore Environmental Values. PFAS source mass discharge management in the FTG source area was therefore considered prudent as part of the redevelopment works to reduce PFAS mass discharge from the Site to the surrounding environment. An additional benefit of the management and mitigation measures (primarily capping and containing PFAS impacted soils) implemented was to allow Defence to repurpose the land to support Defence capability and training.

Using the PMAP as the principal guidance document for PFAS management at the Site, it is important to note that the management and mitigation measures completed at the Site address some, but not all PMAP actions identified. Some actions relate to ongoing administrative controls and monitoring over various time periods (refer to Section 11 for all actions).

Based on the outcomes of the site characterisation phase, it was demonstrated that there were no drivers for active remediation to decrease risk to human health and the environment, or for the restoration of Environmental Values. The first key decision point (No Active Remediation Action Required) outcome was 'yes', as shown in Figure 5.1. Consequently, the Site can transition to long-term management and monitoring (i.e. LTEMP). Any clean-up actions undertaken will be on a voluntary basis to reduce mass discharge into the environment, rather than to manage and mitigate risks and /or restore impacted Environmental Values.

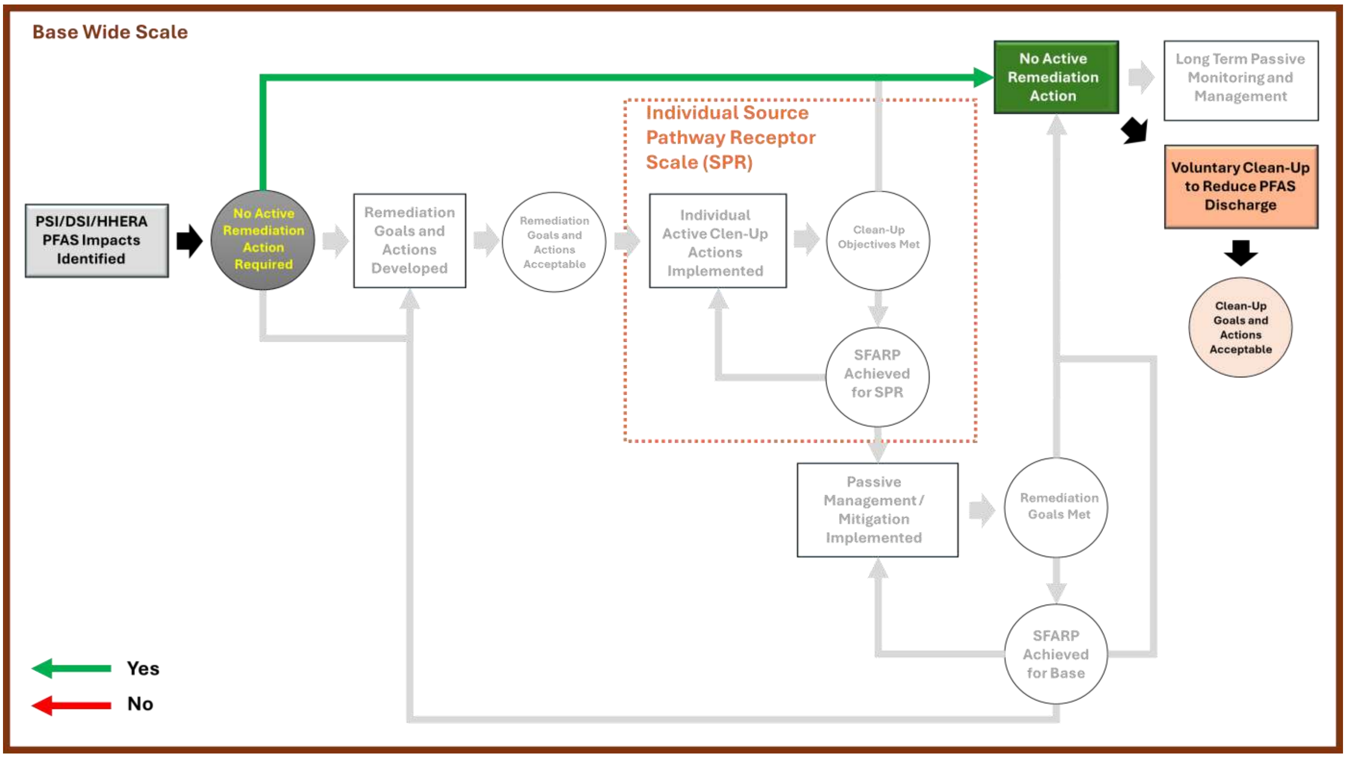


Figure 5.1 Conceptualisation of assessment and decision process for this Site.

The following sections discuss the management and mitigation measures undertaken on-Site on a voluntary basis as part of a Base redevelopment program.

TA’s opinion on the decision process for PFAS management and mitigation at the Site.

The assessments undertaken at the Site have provided sufficient information to identify SPR linkages that may be at risk of characterised PFAS contamination. The robustness of this information has allowed the TA to establish if the decision process is appropriate for managing and mitigating the identified risks.

6. Cleanup drivers

Defence's objective, as outlined in the PMAP, is to manage risks, through avoiding or minimising exposure to PFAS contamination from Defence property to human health and ecological receptors. Measures to meet the overall objective include:

– Implementing practicable solutions to prevent or minimise the migration of PFAS beyond the Defence property boundary through:
  - Reducing the source mass of PFAS contamination.
  - Blocking or diverting the migration pathway of the contamination from the source to receptors.
– Working to protect the community from exposure while practicable solutions are underway

Managing and mitigating PFAS mass discharge from on-Site sources and from the Site boundary will be the primary measures to achieving Defence's objective.

6.1 Objectives of cleanup

In the absence of unacceptable risk to Environmental Values, Defence's overall cleanup objective at this Site is not driven by risk to human health and the environment and /or detrimental impacts on Environmental Values, but rather by an aim to further decrease PFAS mass discharge as part of an opportunistic and voluntary base redevelopment program. Therefore, the objective of the management and mitigation measures undertaken at the Site complied with the spirit and of the GED, which requires decreasing emissions to the environment as far as practicable even when risk to human health and the environment is low and acceptable and there are no detrimental impacts on Environmental Values to require action under the EP Act 2017.

The TA recognises that there may be technical, logistical, financial and sustainability constraints that limit the practicability of achieving Defence's overall cleanup objective and a long-term aspirational goal of restoring Environmental Values or ceasing any discharge of PFAS into the environment with a defined timeframe. As described above, interim measures need to be adopted. To expand on the practicable solutions outlined in the PMAP, these can include measures such as described below:

– Reducing the source mass discharge of PFAS contamination:
  - Elimination of AFFF that contain PFAS compounds from firefighting activities and training. This measure has already largely been met across the Defence estate, resulting in removal of the primary PFAS source.
  - Removal and destruction or immobilisation of PFAS compounds from impacted environmental media to decrease source mass discharge.
– Blocking or diverting the migration pathway of the PFAS contamination from the source to receptors:
  - Isolation of PFAS impacted source zone media to decrease mass loading to the environment.
  - Management of exposure pathways to limit exposure of relevant receptors to PFAS impacted media to maintain risks at low and acceptable levels.

TA's opinion on cleanup objectives

The TA acknowledges that Defence's overall cleanup objective is nonessential in the context of this Site. There are no risks or restoration of Environmental Values drivers. Instead, the management and mitigation measures undertaken will assist in further decreasing the PFAS mass discharge to the environment.

6.1.1 Source mass

PFAS mass in each source area is discussed below.

6.1.1.1 FTG

Golder 2023c, calculated a PFAS mass estimate of 8.31 kg (PFOS+PFHxS) for the FTG (top 3 m). As the management and mitigation measures undertaken in this source area were completed on an opportunistic basis rather than in response to risk mitigation, the lack of mass removal and treatment objectives was not considered to represent a critical data gap in assessing cleanup success.

No robust and defensible estimate of PFAS mass prior to cleanup was available for the remaining source areas. This was due to varying modelling methods employed to calculate the mass, creating an unreliable data set. Given there is limited impacts to Environmental Values, this was not considered to be a significant data gap.

6.1.1.2 South Creek Wetlands associated with FTG, Fire Station and Ornamental Lake and Former Sewerage Treatment Plant

Soil impacts are present in the saturated zone and may be contributing to mass discharge and mass flux within the sources and groundwater. While there is a lack of characterisation with respect to discharge and flux, this was not considered material in the context of the risk profile and scale of impact. This PFAS mass was relatively diffuse across these areas resulting in challenging/impracticable cleanup measures required to decrease this mass and provide a net environmental benefit.

6.1.1.3 Secondary on-Site source areas

Secondary on-Site source areas include:

- Sediments in the surface water drainage network and water courses.
- Sorbed and diffused mass in the soils over the groundwater impact zone.

While there is a lack of characterisation with respect to mass, discharge and flux associated with the secondary sources potentially present, this was not considered material in the context of the risk profile and scale of impact.

TA's opinion

The TA considers that in the context of risks to human health and environment being low and acceptable and there not being any detrimental impacts to Environmental Values, the limited mass discharge and flux characterisation associated with primary and/or secondary sources was not considered to limit decision making with respect to cleanup objectives and actions. Therefore, further characterisation of primary and secondary sources and their contribution to the overall mass discharge from the Site into the environment was considered to have been adequately characterised.

6.1.2 Mass discharge and mass flux

The risk to Environmental Values posed by each source is a combination of:

- Concentration in the solid media that constitutes the source mass.
- The leachability and volume of leachate that constitutes source mass discharge.

Source mass discharge (SMD) contributes to the overall PFAS mass flux (velocity) and mass that moves along each pathway (pathway mass discharge) that leaves each source area and cumulatively discharges into the environment.

As noted in Section 6, Defence's objective is to reduce mass discharge from the Site through a series of one or more cleanup actions that decrease source mass and or pathway mass discharge. Each cleanup action aims to decrease loading of PFAS compounds into the environment. This is a key consideration in supporting management and mitigation action decisions. There were no mass discharge estimates calculated for the source areas prior to cleanup, as there are no risk or environmental drivers for remediation actions. Therefore, no mass discharge and mass flux reduction objectives were set.

The TA considers that the lack of knowledge on mass discharge and mass flux prior to cleanup actions being undertaken was not considered to represent a data gap as the PFAS management and mitigation measures undertaken in the FTG that also contribute to the South Creek pathway were completed on an opportunistic and voluntary basis rather than in response to risk mitigation.

The site characterisation identified that the PFAS concentrations in surface water of the historic FTG lagoon and in the groundwater was historically contributing to PFAS migration into South Creek, both through direct surface water flow and groundwater discharge pathways. This review has established that the historic natural drainage pathway, visible in the 1968 aerial photograph, was likely a material pathway and may continue to serve as a preferential pathway for perched groundwater migration.

As noted within the DSI (Aurecon 2018), the South Creek wetlands have potentially developed as a material secondary PFAS source. The sampling completed within South Creek during the DSI, has confirmed the FTG (RAN SSSS) and the South Creek wetland are the primary contributors of PFAS mass discharge from the Base into the surrounding environment. However, based on available data and information, the relative contributions between the two source areas cannot be assessed at this point. Therefore, there is insufficient information to develop a reliable mass flux estimate for the surface water and/or groundwater pathways prior to management and mitigation.

TA's opinion

The TA considers, with respect to other primary and secondary sources, that while there is a lack of characterisation with respect to mass discharge and mass flux associated with these sources, this was not considered material given that the risk to human health and the environment were low and acceptable and there were no detrimental impacts to Environmental Values. Consequently, the TA considered it reasonable that residual PFAS impacts can be managed through implementation of standard Defence OHS, environmental and construction environmental management plans.

6.2 Active management and mitigation option analysis

The FTG was the only PFAS source area that could be opportunistically cleaned up as part of the Base redevelopment works. An analysis of active management and mitigation measures including cleanup options was undertaken by Golder (2021a) for the FTG. Four were analysed, including:

1. Immobilisation of PFAS impacted soil.
2. Capping of PFAS impacted soil and concrete.
3. Ex-situ thermal destruction (soil and concrete).
4. Storage of PFAS impacted soil and concrete within an on-Site containment cell.

Golder (2021a) estimated the following approximate volumes of PFAS impacted materials within the FTG requiring management included:

- 1,000 m^3 of PFAS impacted concrete and demolition waste from the demolition of FTG infrastructure.
- 6,800 m^3 of PFAS impacted soil from the FTG and a contingency of 6,000 m^3 for additional volume that might be generated from cleanup activities.
- 4,200 m^3 of soil impacted with PFAS and leachable lead, sourced from the former gun range to the north of the FTG, and was brought to the FTG for management.

Design considerations for each management and mitigation option considered are summarised in Table 6.1. The selected option was primarily based upon technical, logistical and financial considerations.

Table 6.1 Active management and mitigation options analysis (Golder 2021a)

Option	Considerations	TA's opinion
1. Immobilisation of PFAS impacted soil	Addressed PFAS waste through immobilisation. Additional consideration needed for treatment of lead impacted material. Did not address how PFAS impacted concrete will be managed. Regular surface water and groundwater monitoring was needed. Onsite management option. Required long term monitoring.	PFAS immobilisation in concrete is generally considered ineffective. PFAS immobilisation in soils has a track record of success and has been successfully implemented at Defence sites. The immobilisation of lead in soils by the same agents used to immobilise PFAS is ineffective. The TA agrees that use of this option as a sole management and mitigation action was not practicable and would not achieve the cleanup objectives set.
2. Capping of PFAS impacted soil and concrete	Addressed all three waste streams. Used existing cell infrastructure. Groundwater intercepting impacted waste needed to be considered. Onsite management option. Required long term monitoring.	This option could deal with all PFAS and lead in all impacted media. However, the effectiveness may have limitations as moisture ingress may still occur through interflow and evapotranspiration, leading to leachate generation, albeit at a reduced rate. This option would also reduce Defence capabilities in terms of restricted reuse of the area. The TA agrees that the use of this option as a sole management and mitigation action was not practicable and would not achieve the cleanup objectives set.
3. Ex-situ treatment (soil and concrete)	Addressed PFAS and concrete waste streams. Additional consideration needed for treatment of lead impacted material. Ex-situ treatment option, involving excavation and transport of waste to a treatment facility. After treatment, a licensed disposal facility needs to be considered.	This option could meet the cleanup objectives with respect to destruction of PFAS rather than immobilisation. But this option could not deal with the lead impact. Further, this option would require considerably higher logistical and financial resources compared to other options. The TA agrees that the use of this option as a sole management and mitigation action was not practicable and would not achieve the cleanup objectives set in an effective and efficient manner.
4. Storage of PFAS impacted soil and concrete within an on-Site Containment Cell	Addressed all three waste streams. Required long-term monitoring. Engineered design to contain impacted soil and limit water infiltration. Onsite management option.	This option can deal with the PFAS and lead impacted media and effectively reduce leachate generation, resulting in reduction in mass discharge and flux in an effective and efficient manner. This option would also allow Defence to maintain capability by making the FTG area suitable for reuse. The TA agrees that this option would allow use of a single management and mitigation action to achieve the cleanup objectives set in a practicable manner.

6.2.1 Technical considerations

6.2.1.1 Option 1 – Immobilisation of PFAS impacted soil

This option involved removing PFAS impacted soil and blending the excavated soil with a commercially available additive. The additives proposed, Rembind® and Matcare®, were specific to PFAS and not lead. Additional lead stabilisation additives would need to be considered. This option also did not address how PFAS impacted concrete would be managed. Regular surface water and groundwater monitoring would be necessary, including the development of a sampling plan to ensure leachability compliance. Consideration should be made for the product lifespan of the additive.

6.2.1.2 Option 2 - Capping of PFAS impacted soil and concrete

The option aimed to limit water infiltration into existing containment cells through the application of an impermeable surface cap which could be constructed of concrete, asphalt or engineered liner/fill surface. for the Design consideration is needed if a groundwater pathway to the containment cells containing PFAS impacted soil and concrete exists. A regular monitoring program and sampling plan would need to be developed, also including a cap inspection to ensure no water can enter the containment cell.

6.2.1.3 Option 3 – Ex-situ thermal destruction treatment (soil and concrete)

Technically, this option presented viable for the destruction of PFAS in the soil, however the leachable lead within the soil may have additional disposal requirements. Consideration would be needed for an offsite landfill with an acceptance criterion suited to the treated soil. Safety for the treatment facility when treating lead materials needed to also be considered. Trials would be needed to inform treatment and disposal.

6.2.1.4 Option 4 – Storage of PFAS impacted soil and concrete within an onsite containment cell

This option presented the best balance between technical, logistical and financial aspects. Encapsulation is a proven method that can deal with a wide range of contaminants using established and proven construction methods, durability and maintenance requirements. This option can deal with PFAS impacted concrete and soil, as well as lead impacted soils utilising a single technology that would require limited ongoing maintenance and monitoring compared to the other options considered.

6.2.2 Logistical considerations

6.2.2.1 Option 1 – Immobilisation of PFAS impacted soil

The impacted soil would need to be excavated, then blended with an additive to immobilise PFAS and other contaminants of concern. This option would have been completed on-Site.

6.2.2.2 Option 2 – Capping of PFAS impacted soil and concrete

This option involved the design and implementation of an engineered low permeability surface capping layer which could be constructed of concrete, asphalt or engineered liner/fill surface. As soil and concrete containment cells are already existing, the option could manage the PFAS and leachable lead impacted soil on-Site.

This option will be logistically challenging if groundwater intercepts the Containment Cell. A groundwater vertical cut off wall may need to augment the surface cap.

6.2.2.3 Option 3 – Ex-situ thermal destruction treatment (soil and concrete)

The ex-situ thermal destruction of PFAS involves taking the impacted soil and concrete off-Site, treating it and then disposing off-Site. This would require large volumes of soil to be transported.

6.2.2.4 Option 4 – Storage of PFAS impacted soil and concrete within an onsite containment cell

This option required an engineered containment cell and cap which would need to be constructed on-Site. Excavation of impacted soil and concrete and transport into the cell would be required. This was able to be completed within the project timeline. Regular monitoring was also required.

6.2.3 Financial considerations

6.2.3.1 Option 1 – Immobilisation of PFAS impacted soil

Financial considerations for this option included the purchasing of the commercial additives, excavation of soil volume, mixing of soil in-situ with a commercial additive. Additionally, long-term monitoring programs needed to be developed to ensure that the solution met leachability requirements.

6.2.3.2 Option 2 – Capping of PFAS impacted soil and concrete

This option used existing infrastructure in the FTG and hence would only need to be costed for the impermeable surface cap which would vary in cost depending on the construction material used.

The cost for this option would increase if the groundwater assessment showed that there was a pathway for groundwater to intercept the PFAS impacted material. In which an additional impermeable vertical liner around the PFAS impacted material will need to be built.

There will also be costs associated with a regular monitoring program to ensure leachability reduction has been achieved through instatement of a cap.

6.2.3.3 Option 3 – Ex-situ thermal destruction treatment (soil and concrete)

Financially this option was least beneficial as it involved excavating the soil and concrete and transporting it to a treatment facility. Additionally, there would be costs for further disposal depending on the quality of the materials after treatment.

6.2.3.4 Option 4 – Storage of PFAS impacted soil and concrete within an on-Site containment cell

The major costs associated with construction of an on-Site containment cell were the engineered design and construction of the containment cell and impermeable cap. Ongoing costs were needed for monitoring, inspection and maintenance of the cap.

TA's opinion on cleanup objectives and options

The objectives considered and set for the management and mitigation measures were not driven by scale and extent of impacts and any associated risk to Environmental Values, but rather by opportunistic circumstances associated with an infrastructure redevelopment completed as the Base. As such the cleanup objectives were considered reasonable and appropriate in that context of the cleanup drivers.

A suitable range of proven and reliable options for management and mitigation measures in the context of the cleanup drivers were considered. The options were assessed for their technical, logistical, and financial merits in a robust and defensible manner, considering the cleanup drivers.

The adoption of an encapsulation approach (Option 4) as a suitable management and mitigation action was considered to provide a practicable and effective cleanup method for the range of contaminants (PFAS and lead) and impacted media (concrete and soils) that needed to be managed.

7. Management and mitigation approach for the Site

The on-Site containment cell was selected as the best approach to manage the PFAS impacted waste material within the FTG considering financial and time constraints. Design objectives were considered in the Golder (2021b) report which are summarised below:

- Limit inflow of water from precipitation, surface water and groundwater into the contaminated materials. This aimed to mitigate the risk of PFAS being transported through surface water and groundwater due to the high solubility of PFAS.
- Collect PFAS and lead impacted liquid (leachate) for treatment. This was considered most likely to be generated during construction and early phase operation.
- Limit advective seepage of leachate into the groundwater or surface water environment.
- Enable future recovery of stored materials by separation of the PFAS, and PFAS and lead impacted materials and leachate.
- Provide a robust containment solution.
- Enable performance monitoring of the containment system via periodic assessment of the leachate collection system.

Golder designed the containment cell in consideration of the soil volume that needed to be managed. This included 11,000 m^3 of PFAS impacted soil and demolition material, 4,500 m^3 of lead contaminated soil and a further contingency to account for potential additional volume. The cell was designed to manage up to 20,000 m^3, with an expected volume of 17,900 m^3. Two distinct areas were defined in the cell layout:

- Cell A contained PFAS impacted soil and also leachable lead contaminated soil which have been placed separately within Cell A.
- Cell B was loaded with PFAS impacted material from the demolition and FTG cleanup activities.

The containment cell layout depicted in the Golder (2021b) is shown in Figure 7.1.

Figure 7.1 ***Containment cell layout designed by Golder (2021b)***

The containment cell design comprised the following:

– **Baseliner** – A composite liner that consisted of a geosynthetic clay liner and 1 mm thick Ethylene Interpolymer Alloy Geomembrane above prepared subgrade. A leachate collection system was installed above the liner consisting of a drainage geocomposite layer and leachate collection pipe network. Selected PFAS impacted soils overlaid the liner, with a thickness of 300 mm on the cell floor and 500 mm thickness on the side slopes. Figure 7.2 displays the baseliner design completed by Golder (2023c).

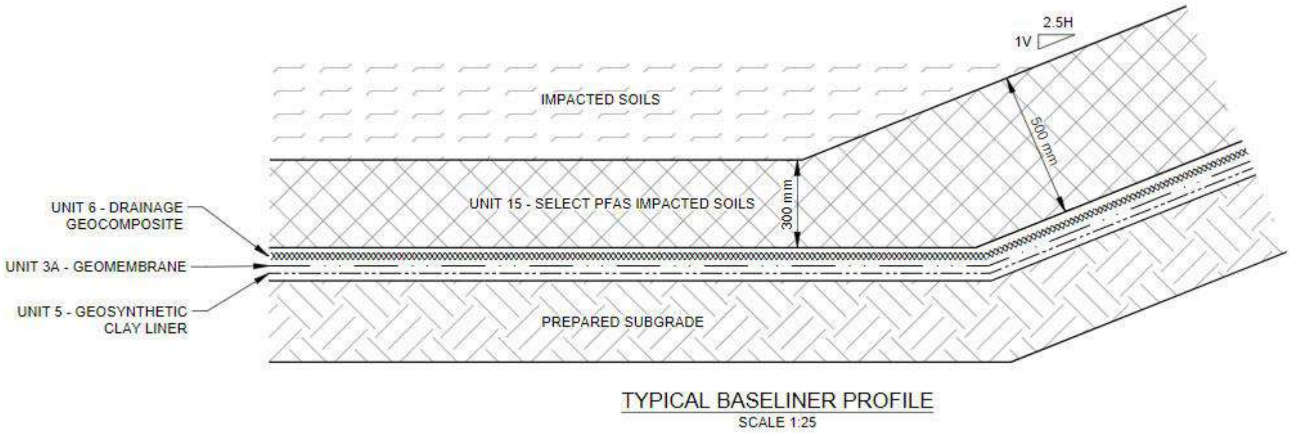


Figure 7.2 Baseliner design for the containment cell (Golder 2023c)

– **Capping layer** – The capping layer included a 750 mm thick cover soil layer which overlaid a cushion geotextile, a 1.5 mm thick Linear Low-Density Polyethylene (LLDPE) geomembrane and a geosynthetic clay liner. A network of drains was placed above the LLDPE geomembrane layer. The cap was grassed to limit soil erosion with a network of surface swale drains installed to collect stormwater. Figure 7.3 displays the cap liner design completed by Golder (2023c).

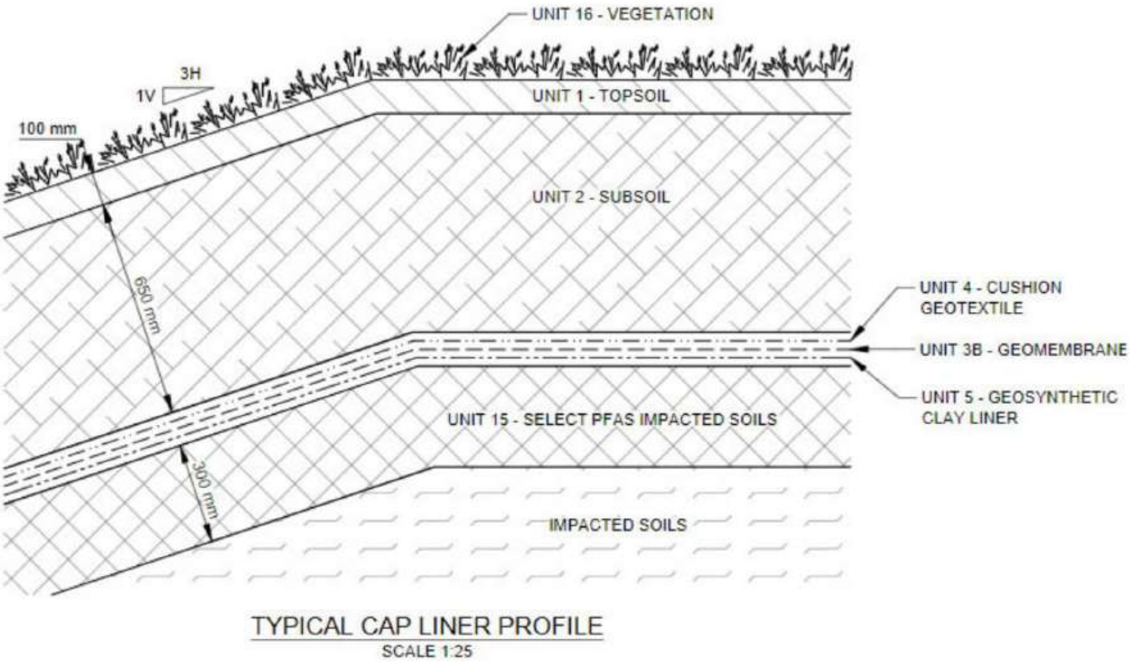


Figure 7.3 Cap liner design for the containment cell (Golder 2023c)

Contaminated material was placed in between the base liner and cap liner, these two features limit water entering the contaminated material, therefore limiting PFAS source mass discharge. Vertical containment walls were not considered as the groundwater level was found to be below the containment cell where the contaminated material was placed and the seepage risk from groundwater was considered negligible. The design included a leachate collection system which was expected to collect water that had entered the containment cell during construction.

There was limited information provided in Golder (2023c) regarding the interaction between PFAS and the baseliner geomembrane. This was primarily since PFAS has not existed long enough to study performance of commercially available geosynthetic materials.

The geosynthetic materials that Golder had selected were specifically designed for containment of PFAS and lead. The cell was constructed in accordance with best practice landfill design in which the materials are expected to have a service life in the order of hundreds of years. Correct maintenance of the cap liner, regular monitoring, and construction of the containment cell in accordance with the design documents were expected to maintain optimal service life of the design.

TA's opinion on management and mitigation approach

The adopted management and mitigation approach (i.e., encapsulation) used appropriate materials and design specifications based on proven methods and performance in a range of Australian settings.

The design and specifications for the encapsulation cell was considered appropriate and would provide a practicable and effective means of decreasing PFAS source mass discharge from the FTG area.

8. Summary of management and mitigation measures

The scope of works completed by Golder (2023c) in the construction phase of the containment cell are summarised in Table 8.1.

Table 8.1 Summary of management and mitigation measures completed (Golder 2023c)

	Summary of works completed
Site Management	A Site Management Plan (SMP) that met project requirement set out by Lendlease (Managing Contractor). Establishment and demobilisation. Tracking of material movements on-Site. All Environmental Management required to complete the cleanup works. Control of all stormwater including storage, treatment and disposal during the cleanup works. Management of all traffic related to the cleanup works (both on-Site and off-Site). Identification of utilities and utility alignments, buildings, trees and other Site features to be retained and protected during the cleanup works.
Site demolition – Refer to Section 8.2	Removal and treatment of water within the Collection Pond. Decommissioning of existing groundwater wells. Demolition of all surface and subsurface features not shown as ‘Features To Be Retained’ including hardstand, sheds, structures, tanks, slabs, footings, pipes, trees, and fencing. Recycle (if possible and subject to PFAS contamination) any components of the demolition. Mulching any vegetation removed from works area and stockpiling for reuse on the Base. Stockpiling for placement of all other demolition materials in the Containment Cell.
Soil Cleanup Excavation – Refer to Section 8.3	Excavation of the known areas of PFAS contaminated soil to the required targeted cleanup design depths with placement of the soil in stockpiles or directly into the Containment Cell, as required. Additional excavation of those areas of soil contamination that become apparent during excavation activities and environmental investigation as part of the cleanup works undertaken. Placement of nominated materials from the demolition and cleanup works into the Containment Cell (Cell B). Loading and carting of the leachable lead contaminated soil stockpiles from on the Base and placement into the Containment Cell (Cell A), separate to the PFAS impacted soil. Supply of fill from the Base Reuse Stockpiles to backfill excavations. Placement and compaction of the fill within the excavations. The Containment Cell will be managed under an Aftercare Management Plan (AMP) (Golder 2023b). Refer to Section 8.7 for further details of the AMP.

8.1 Management and mitigation responsibilities

Parties involved in the Site management and mitigation measures are presented in Table 8.2.

Table 8.2 Roles and responsibilities

Role	Party	Responsibility description
Project Manager/Contract Administrator (PMCA)	RPS	Contracted to Defence to provide project/contract management oversight of infrastructure works.
Managing Contractor	Lendlease	Contracted by Defence Capital Facilities and Infrastructure Branch (CFI) to undertake infrastructure development (including cleanup) works on the Defence estate.
Civil Works	Delta Group	Contracted by Lendlease to undertake the Base Redevelopment Civil Works.

Role	Party	Responsibility description
Remediation Subcontractor	LMI Group Investments	Contracted by Delta to undertake the FTA cleanup works and PFAS Containment Cell construction.
Water Treatment Contractor	Synergy Resource Management Pty Ltd	Contracted by Lendlease to treat PFAS impacted water from the Base redevelopment works including the cleanup works.
Environmental Consultant/Design Consultant	WSP Golder	Contracted by the Managing Contractor to advise on, undertake testing, provide technical advice or develop proposals/plans/reports/designs associated with the cleanup works. Undertaking the role of Civil Quality (CQA) Engineer for the Containment Cell construction.
Technical Advisor	Dr. Peter Beck, GHD	The accredited Environmental (contaminated land) Auditor responsible for reviewing/providing an opinion on the Addenda Validation Plan (AVP), the validation report and post cleanup works monitoring.
PMAP Implementation/Lead Consultant	Aurecon and Stantec	Contracted by Defence to update and implement the PMAP and advise on the PMAP implementation, undertake environmental testing, provide technical advice or develop proposals/plans/certificates.

8.2 Site demolition

Demolition of above ground structures, concrete slabs and foundations commenced at the FTG in approximately February 2021. Water was pumped from the stormwater pond and treated through the Base water treatment system, which is run by Synergy.

Demolition materials for on-Site disposal in Cell B included:

– HDPE tanks and a former pond liner were shredded to pieces of less than 1 m ready for disposal.
– Concrete which was crushed and initially stockpiled awaiting Containment Cell construction. A total of approximately 2,400 m^3 was crushed to 20 mm particle size.
– Minor volumes of other unspecified waste which was shredded.

Demolition materials for off-Site disposal included:

– Steel, which was sampled, and EPA classified for off-Site recycling (to Infrabuild Recycling) and smelting.
– Sludge that was encountered at the base of the three ASTs in the FTG. Samples were taken from each AST and classified by Golder. Approximately 24 m^3 of sludge was transported off-Site for treatment at the Renex treatment facility. A waste classification letter is provided in Appendix H of Golder 2023c. Figure 8.1 presents the FTG following demolition of infrastructure.

Figure 8.1 FTG cleanup area (Golder 2023c)

8.3 Cleanup excavation and backfilling

PFAS impacted soil was excavated from Cell B following demolition works. The majority of soils in Cell B (RA06, RA07, RA08 and RA09) were excavated and temporarily stockpiled in another zone of the management area. Remaining soils in the Southern Validation Area excavation were successfully validated, meeting the initial remediation criterion. This occurred before refinement of the AVP (Golder 2021a) validation approach.

Containment Cell B was then constructed, backfilled with the excavated impacted material and compacted to a suitable standard. Further excavated material in the FTG (RA01, RA02, RA03, RA04 and RA05), was then directly placed in Cell B. When Cell B material excavation was finalised, construction of Cell A commenced. These excavations were validated in accordance with the AVP (Golder 2021a) validation approach. Additional work areas containing PFAS impacted soil (AW1 to AW16) were also excavated and placed in Cell B. A summary of final volumes of material in Cell B and management area excavation details is provided in Table 8.3.

Table 8.3 Final volumes of material placed into Cell B and management area excavation details (Golder 2023c)

Management area	Depth (m)	Proposed excavation area (m^2)	Base works in-situ volume (m^3)
RA01	1	47	47
RA02_A	3	156	469
RA02_B	3	76	228
RA03_A	0.5	566	283
RA03_B	0.5	510	255
RA03_C	0.5	981	490
RA04	2	207	415
RA05	1	137	137
RA06	1	227	227
RA07	0.5	185	92
RA08	1	2,132	2,132
RA09	2	255	509
Initial excavation volumes (base works) (m^3)			5,284
Additional excavation works (m^3)			5,699
Total PFAS impacted soil (m^3)			10,983
Crushed demolition materials (m^3)			2,400
Total volume of material in Cell B (m^3)			13,383

To support cell construction, additional material was excavated within the FTG from the locations listed in Table 8.4.

Table 8.4 Additional materials supporting cell construction

Location	Depth (m)	Volume (m^3)	Requirements & comments
South West Borrow Pit located outside of the western embankment of the containment cell	3 - 4	3, 000	Category 3 or 4 reuse under the Defence PFAS Construction and Maintenance Framework 3.0 (CMF V3.0). Risk assessment for the reuse of the borrow pit material in the Containment Cell construction.
East Borrow Pit outside the Eastern embankment	3	Unknown	Category 3 or 4 reuse under the CMF V3.0. Temporary capping of the PFAS impacted material placed in Cell B whilst Cell B construction was delayed due to weather. The final cap and liner were constructed over this temporary capping material.
Imported material	NA	Unknown	Golder Associates Pty Ltd (2023a) HMAS Cerberus PFAS Impacted Materials Cell Construction Report, dated 2023, as referenced in Golder 2023c. Anecdotal information provided suggest the imported material was suitable.

All cleanup excavations were backfilled with stockpiled material from the broader Base redevelopment works. Stockpiled materials used in backfilling were tested to meet requirements of Category 3 and 4 PFAS impacted material under the August 2021 update to the Defence PFAS Construction and Maintenance Framework 3.0 (CMF V3.0). No soil had been disposed of off-Site.

8.4 Construction environmental management

Cleanup works for the FTG were undertaken in accordance with the following environmental management plan:

– Delta Group (2020), Environmental Management Plan, HMAS Cerberus Redevelopment – Phase 2 Civil Works, dated 23 June 2020.

Lendlease, the Managing Contractor had confirmed that Golder had fulfilled their duties under the environmental management plan with no major non-conformances in an email to WSP Golder, dated 1 August 2022.

There was also a construction quality assurance report for verification that the Containment Cell had been constructed to the requirements of the Technical Specification as referenced in Golder 2023c as titled Golder Associates (2021) PFAS Impacted Materials Cell - Technical Specification, dated 4 February 2021. The final finish and site levels are provided in the construction quality assurance report for the PFAS Impacted Materials Cell (Golder 2023a, as referenced in Golder 2023c).

8.5 Validation methodology

A Sampling, Analysis, and Quality Plan (SAQP) developed by Golder (2021b) set out requirements to achieve PFAS mass discharge reduction through validation soil sampling of the excavation walls and base. This was to demonstrate that PFAS impacted soils were excavated and contained within the Containment Cell. This was supported with modelling of the nature and extent of PFAS impacts to achieve PFAS mass emission reduction through encapsulation of the impacted material.

The methodology used by Golder (2023c) that achieved outcomes of validation, were as follows:

– Wall samples were collected at a maximum 10 m horizontal intervals (or 1 sample per wall) with a 1 m vertical spacing generating a minimum sample density of 1 sample per 10 m^2 for the excavation wall.
– Base samples were taken on an approximate 10 m x 10 m grid, or a minimum of one base sample per excavation.
– All validation samples were analysed for PFAS (28 suite), with additional TPH analysis conducted in the eastern portion of the FTA excavation, as per identified contaminants of interest.

The PFOS+PFHxS concentration at each validation location was assessed against the 3D modelled concentration (based on the October 2021 data) in consideration of the following:

– Should the concentration be the same or less than the modelled concentration for the specific location, no further cleanup was considered.
– Should the concentration be greater (considered to be more than 10% greater) than the modelled concentration for the specific location, the impact of the result was reassessed via modelling to further consider its impact.
– Should the influence of the elevated result impact the target outcome, further cleanup works were defined to reduce the impact.
– Otherwise, no further cleanup works will be considered.

8.6 Validation results

8.6.1 TRH

The validation sampling results of TRH (C_{10} – C_{16}) confirmed that exceedances in the east of the FTG had been excavated with no further elevated levels above the management levels identified. Four exceedances of ecological criteria for coarse soils (170 mg/kg) were detected out of a total of 47 TRH (C_{10} – C_{16}) samples collected. TRH concentrations in soil ranged from 270 – 530 mg/kg at an approximate depth of 1 m. Three of these samples were located under the eastern edge of the Containment Cell and one sample, BHCV20, was located east of the Containment Cell. The exceedances were assessed to be unlikely to pose an unacceptable ecological risk to flora and fauna.

8.6.2 PFAS mass and source mass actions

PFAS mass modelling was completed in accordance with the AVP (Golder 2021a). The AVP estimated the source mass treatment which was achieved by the cleanup actions implemented. The model was revised from October 2021, estimating a total 8.31 kg of PFOS+PFHxS present in the top 3 m of the soil profile with a large PFAS mass located in the north of the FTG, and a smaller mass towards the south (Golder 2023c).

Mass estimates of PFOS+PFHxS remaining in the FTG, summarised by concentration intervals as provided by Golder (2023c), are displayed in Table 8.5. A total of 5.75 kg of PFAS (PFOS+PFHxS) was encapsulated in the Containment Cell.

Table 8.5 Final expected mass of PFOS+PFHxS remaining within 3 m by concentration interval (Golder 2023c)

PFOS+PFHxS concentration interval (µg/kg)	Estimated PFOS+PFHxS mass prior to cleanup (kg)	Estimated PFOS+PFHxS mass (kg) remaining post cleanup	% Mass of PFOS+PFHxS remaining in concentration interval
< 0.01	0.00	0.00	100.0%
0.01-0.1	0.00	0.00	100.0%
0.1-0.5	0.00	0.00	98.1%
0.5-1.0	0.00	0.00	96.8%
1.0-2.0	0.01	0.01	96.7%
2.0-5.0	0.02	0.02	95.2%
5.0-10.0	0.06	0.06	92.2%
10.0-20.0	0.17	0.16	80.5%
20.0-50.0	0.64	0.51	54.7%
50.0-100.0	1.18	0.64	36.8%
100.0-200.0	1.75	0.64	24.7%
200.0-400.0	1.55	0.38	11.7%
400.0-600.0	0.75	0.09	4.1%
600.0-800.0	0.53	0.02	2.9%
800.0-1000.0	0.38	0.01	1.0%
1000.0-2000.0	0.92	0.01	0.0%
2000.0-3000.0	0.21	0.00	0.0%
3000.0-5000.0	0.12	0.00	0.0%
> 5000.0	0.02	0.00	0.0%
Approx. total:	**8.31**	**2.56**	**30.8%**

Modelling for PFOS+PFHxS mass flux reduction was undertaken in October 2023. The reduction percentages are displayed in Table 8.6. The project has encapsulated approximately 70% of the PFAS mass above 3 m depth with around 1.1 kg of mass estimated to remain below 3 m. The remaining mass is covered by the Containment Cell, limiting surface water infiltration and therefore limiting contributions to mass discharge.

Table 8.6 PFOS+PFHxS mass reduction modelling summary for the FTG (Golder, 2023c)

	Depth interval (m)	Estimated initial PFOS+PFHxS mass (kg) in above soil profile	Estimated remaining PFOS+PFHxS mass (kg) in above soil profile	PFOS+PFHxS mass reduction
October, 2023	0.0 - 0.5	3.35	0.41	87%
October, 2023	0.0 - 3.0	8.31	2.56	70%

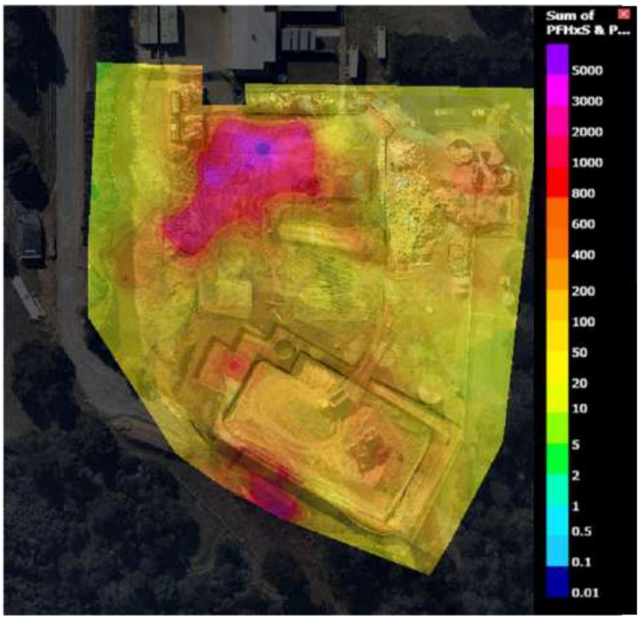
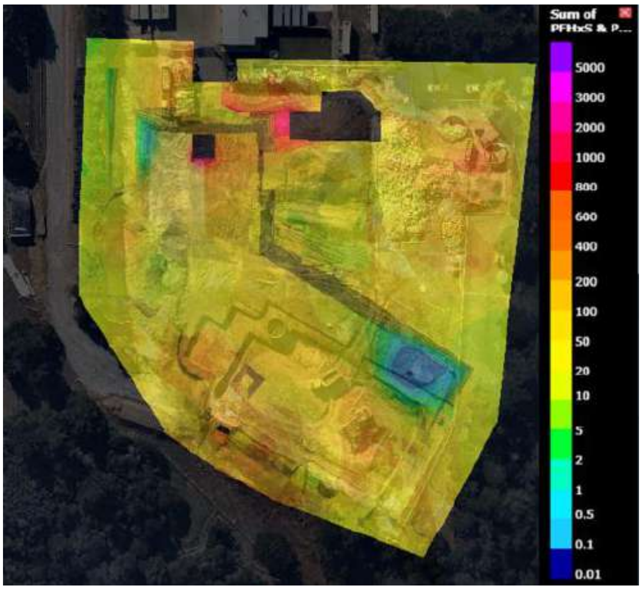
Modelling completed for PFOS+PFHxS mass within the top 0.5 m after cleanup is displayed in Table 8.7.

Table 8.7 Modelling completed for PFOS+PFHxS mass within the top 0.5 m (µg/kg) after cleanup (Golder 2023c)

After cleanup


Modelling completed for PFOS+PFHxS mass within the top 3.0 m before and after cleanup is displayed in Table 8.8.

Table 8.8 Modelling completed for PFOS+PFHxS mass within the top 3.0 m (µg/kg) (Golder 2023c)

Before cleanup	After cleanup
	

TA's opinion on cleanup works completed

The cleanup works of the FTG were implemented in accordance with the proposed approach (i.e., encapsulation). Sampling and validation during the cleanup works, supported by numerical modelling of the nature and extent of PFAS pre and post cleanup activities, demonstrated that around 70% of the estimated PFAS mass in soils was excavated and encapsulated in the Containment Cell. A total of 5.75 kg of PFAS mass was encapsulated in the Containment Cell. The majority of the PFAS mass that remains beyond the Containment Cell is under the cell itself, limiting the potential for rainfall infiltration, further decreasing the mass discharge from the FTG area.

The cleanup works undertaken were in line with the approach proposed, in the context of the management and mitigation driver being opportunistic rather than by risk and impacts to Environmental Values.

8.7 Aftercare Management Plan

An Aftercare Management Plan (AMP) was prepared by Golder (Golder 2023b). The AMP objective was to provide management and monitoring procedures for the Site to assist with the management of environmental risk associated with the Containment Cell and to provide triggers for further action, if required. The AMP is intended to be used to help ensure the Containment Cell is operated and maintained in accordance with the design intent.

The AMP provides roles and responsibilities to ensure the Containment Cell is managed appropriately. Table 8.9 provides a summary of the management requirements outlined in the AMP.

Table 8.9 AMP management requirements (Golder 2023b)

Management requirements	Details
Areas subject to management under the AMP	Given the inert nature of the contained material in the cell, it is unlikely landfill gas or odours will be produced. Therefore, the area subject to management is the containment cell footprint, which has been defined as a contaminated site record (CSR) on the Defence internal database (i.e. Garrison Estate Management System (GEMS) database).
Post closure land use	The area of the Containment Cell will likely be used for passive open space use. Any new development or land use change must be assessed and endorsed by the TA. Any development adjacent to the Containment Cell must undergo a risk assessment to determine if there are any risks associated with the proposed development and whether they can be managed appropriately.
Restrictions on construction	No structures are to be placed on the cell that may impact settlement and the capping system. Deep-rooted vegetation should not be grown on the cap (i.e. >300 mm roots).
Future treatment of contained material	Should it be proposed that the contained material be excavated and treated, a designer with appropriate landfill design experience should be engaged to design the works to facilitate material removal. The designer must also be able to redesign the cell if some material is to remain in-situ. Future excavation must also consider the chemical nature of the materials and be handled appropriately.
Health & Safety & Environmental management	Any excavation of the cell, deeper than 0.5 m must be undertaken in accordance with a site-specific health, safety and environment plan. The plan must consider the potential to encounter soil and waste containing elevated concentrations of PFAS, lead and TRHs.

Management requirements	Details
Inspection requirements	The Containment Cell must be inspected by the Base Estate Maintenance and Operations Project Support (EMOS) at the following intervales: – Monthly for the first 12 months to assess establishment of the site vegetation and post construction performance of the cell. – Three-monthly for the second year after completion. – Six-monthly from thereon. – After large rain events. Features to be inspected for their integrity include: – The cap, surrounding stormwater drain, stormwater outlets, leachate collection system outlets, leachate sumps and landfill gas infrastructure. All inspections will be logged, photographed and recorded by EMOS.
Maintenance	Any maintenance work undertaken, which will impact the cap greater than 0.5 m below the final site level must not adversely impact on the performance of the cap system, cause damage to the cap, including the passive gas venting system and the stormwater infrastructure. All maintenance work will be logged, photographed and recorded by EMOS. Consideration of the following items must form part of the maintenance regime: – Vegetation. – Erosion. – Depressions, ponding and cracks. – Burrowing animals. – Sedimentation of surface water drains. – Repair to specific components of the cell.
Excavation	Excavation within the cell footprint should be avoided. Care must be taken to not damage any cap component including the geomembrane and geosynthetic drainage, leachate sumps, gas vent infrastructure, stormwater outlets or leachate pipes. All excavation works must be recorded.
Leachate sump and leak detection system	The sump and leak detection systems require regular measurement and inspection to ensure leachate levels within the sump are below the liner system.
Leachate sampling and analysis	Leachate in the Cell A and Cell B sumps and leak detection systems will be sampled prior to leachate pumping. Prior to leachate disposal, analysis of samples will be undertaken for PFAS, metals, TRH, major cations and anions, pH and total dissolved solids (TDS).
Flow rate measurement and pumping	The Cell A and Cell B leachate sumps shall be pumped dry using the pumping and disposal system selected for the task. Flow rate measurements must be taken to detect if there have been significant increases in leachate ingress over the inspection period that may indicate a breach of the Containment Cell.
Leachate disposal options	Utilising the analytical data obtained from leachate sample analysis, an appropriate disposal option should be made. Disposal options include the mobile PFAS water treatment system located on the Base or bulk container removal by a liquid waste contractor.
Trigger levels and contingency plan	An increase in flowrates of more than 20% over two monitoring periods triggers the need for the contingency plan: - The significance of the increased flowrate and recommended action for rectification will be made by an appointed environmental consultant. Rectification may include increasing the pumping events, investigation of possible areas of cap or liner leakage, restoration of the cap or part thereof.
Documentation of leachate sump monitoring	Sump monitoring must be reported after each event including: - Methods and results of each monitoring round. - Consolidated summary of flowrates and analytical information from the sumps and leak detection system monitoring. - Assessment of the trigger conditions and contingency actions (if required).

Management requirements	Details
Landfill gas vents	Landfill gas monitoring must be undertaken at two gas venting points on the crest of the cell at quarterly intervals for two years. This is to assess the concentration, composition and rate of gas being generated by the cell. Landfill gas monitoring must be documented after each event.
Review of AMP implementation	After two years of implementation, all AMP records must be reviewed by a TA. This review is due in August 2025.

9. Site conditions after cleanup actions

9.1 PFAS sources

The condition of the PFAS source areas after implementation of management and mitigation measures (i.e. cleanup actions) as established by the TA, are listed in Table 9.1. A summary of the changes to the PFAS source areas and the TA's conclusions are also provided.

Table 9.1 PFAS sources post-cleanup

Source area description	Contaminated site record*	Known & potentially affected media (Aurecon 2018)	Changes to PFAS source areas	TA conclusion
Known primary sources				
FTG	CSR_VIC_000 276 (VT0067)	Soil Concrete pavement Surface waters Groundwater discharge to wetlands	PFAS impacted soil and concrete encapsulated in an engineered cell, resulting in the elimination of mass discharge from around 70% of the impacted material and reduction of mass discharge from most of the remaining impacted soil (Golder 2023c). Groundwater and surface water were not subject to management and mitigation measures directly, but the decrease in mass loading should contribute to a decrease in mass flux in these pathways.	The encapsulation of 70% of impacted soils and decrease in discharge from the remainder of the PFAS impacted soil is anticipated to result in a material decrease in mass discharge from this source and contribute to an overall long-term decrease in mass discharge of PFAS from the Base.
Fire Station/Ornamental Lake	CSR_VIC_000 447	Soil Sediment and surface water in Ornamental Lake Concrete pavement	Anecdotal information suggests that the Ornamental Lake area was remediated as part of the N2197 HMAS Cerberus Redevelopment Project.	PFAS source mass discharge and mass flux are anticipated to reduce.
Former STP	CSR_VIC_000 140 (VT0375)	Sludge/sediment in the lagoon system Soil Collected water in lagoon system Surface water	PFAS impacted media remain within this source area. No management and mitigation measures to remove PFAS mass or decrease mass discharge were undertaken in this source area.	PFAS source mass discharge and mass flux are anticipated to remain unchanged in this source area.
Sullage Pit	CSR_VIC_000 148 (VT0363)	Sediment and surface water from spoil Grass and soil in surrounding area	PFAS impacted media remain within this source area. No management and mitigation measures to remove PFAS mass or decrease mass discharge were undertaken in this source area.	PFAS source mass discharge and mass flux are anticipated to remain unchanged in this source area.

Source area description	Contaminated site record*	Known & potentially affected media (Aurecon 2018)	Changes to PFAS source areas	TA conclusion
Minor primary/secondary source areas				
Sports field	No CSR	Soil	PFAS impacted media remain within this source area. No management and mitigation measures to remove PFAS mass or decrease mass discharge were undertaken in this source area.	PFAS source mass discharge and mass flux are anticipated to remain unchanged in this source area.
Bushfire zone - portion of the eastern Site boundary and in the bush along the south shore of Hanns Inlet	No CSR	Grass and soil	PFAS impacted media remain within this source area. No management and mitigation measures to remove PFAS mass or decrease mass discharge were undertaken in this source area.	PFAS source mass discharge and mass flux are anticipated to remain unchanged in this source area.
Closed Rifle Range Rd Landfill	CSR_VIC_000 137 (VT0365)	Soil Surface water	PFAS impacted media remain within this source area. No management and mitigation measures to remove PFAS mass or decrease mass discharge were undertaken in this source area.	PFAS source mass discharge and mass flux are anticipated to remain unchanged in this source area.
Closed indoor & outdoor swimming pool converted to landfills	CSR_VIC_000 143 (VT0366) CSR_VIC_000 139 (VT0380)	Soil	PFAS impacted media remain within this source area. No management and mitigation measures to remove PFAS mass or decrease mass discharge were undertaken in this source area.	PFAS source mass discharge and mass flux are anticipated to remain unchanged in this source area.
Storm water drains/Off-Site residential sources	No CSR	Surface water and sediment in storm water/interceptor pits and pipes	PFAS impacted media remain within this source area. No management and mitigation measures to remove PFAS mass or decrease mass discharge were undertaken in this source area.	PFAS source mass discharge and mass flux are anticipated to remain unchanged in this source area.
Underground and Aboveground Storage Tank areas	CSR_VIC_000 155 (VT0191) CSR_VIC_000 280 (VT0369) CSR_VIC_000 279 (VT0370) CSR_VIC_000 070 (VT0371) CSR_VIC_000 277 (VT0372) CSR_VIC_000 278 (VT0373)	Concrete and bitumen	PFAS impacted media remain within this source area. No management and mitigation measures to remove PFAS mass or decrease mass discharge were undertaken in this source area.	PFAS source mass discharge and mass flux are anticipated to remain unchanged in this source area.

Source area description	Contaminated site record*	Known & potentially affected media (Aurecon 2018)	Changes to PFAS source areas	TA conclusion
Coal loading area	CSR_VIC_000 138 (VT0367)	Soil	PFAS impacted media remain within this source area. No management and mitigation measures to remove PFAS mass or decrease mass discharge were undertaken in this source area.	PFAS source mass discharge and mass flux are anticipated to remain unchanged in this source area.
Water Filter Wash-down Area and UST (CER01) and ASTs	CSR_VIC_000 069 (VT0192)	Concrete and bitumen Soil	Filters from the water treatment plant at the FTG may have been cleaned in the area near Building 136, which is located north of the FTG and encompassed by CSR area CSR_VIC_000069. No management and mitigation measures to remove PFAS mass or decrease mass discharge were undertaken in this source area.	Likely minor impact. However, information provided in Aurecon 2018 shows that impact may be forming an isolated groundwater plume.
Communications school	No CSR	Soil and surface water	PFAS impacted media remain within this source area. No management and mitigation measures to remove PFAS mass or decrease mass discharge were undertaken in this source area.	PFAS source mass discharge and mass flux are anticipated to remain unchanged in this source area.
Former dry-cleaning facility	CSR_VIC_000 149 (VT0368)	Soil Concrete and bitumen	PFAS impacted media remain within this source area. No management and mitigation measures to remove PFAS mass or decrease mass discharge were undertaken in this source area.	PFAS source mass discharge and mass flux are anticipated to remain unchanged in this source area.
Powerhouse	CSR_VIC_000 147 (VT0374)	Concrete and bitumen	PFAS impacted media remain within this source area. No management and mitigation measures to remove PFAS mass or decrease mass discharge were undertaken in this source area.	PFAS source mass discharge and mass flux are anticipated to remain unchanged in this source area.
On-site residential sources	No CSR	Surface water Soil	PFAS impacted media remain within this source area. No management and mitigation measures to remove PFAS mass or decrease mass discharge were undertaken in this source area.	PFAS source mass discharge and mass flux are anticipated to remain unchanged in this source area.
Notes: *Assigned by Defence				

9.2 PFAS transport pathways

No direct management and mitigation measures were undertaken with respect to the PFAS mass flux in the transport pathways. For example, there was no actions undertaken to intercept groundwater and surface water flows, as there was no unacceptable risk to Environmental Values. The primary focus was to reduce PFAS source mass discharge through soil cleanup activities at the FTG.

Transportation of PFAS through diffusion and leaching mechanisms in concrete, sediment and soil are considered relevant transport pathways, in addition to insitu biotransformations in sediments and soil.

9.2.1 Infrastructure

A total of approximately 2,400 m^3 of PFAS impacted concrete was removed from the FTG and crushed to 20 mm particle size. This crushed concrete was disposed of in Cell B of the Containment Cell. PFAS impacted infrastructure remains in other source areas as set out in Table 9.1.

9.2.2 Sediment

Anecdotal information suggests sediments were removed from the Ornamental Pond during the stormwater infrastructure upgrades and placed in the footprint of the proposed Containment Cell (Aurecon 2021). Therefore, some PFAS mass has been removed but not quantified. PFAS impacted dust, blown from the FTG is anticipated to no longer be occurring, therefore a reduction in sediment accumulation in this area of the Site can be anticipated.

9.2.3 Soil

9.2.3.1 Concentrations – Soil

Most of the PFAS mass in affected soils at the FTG source area were excavated and encapsulated in the Containment Cell. A minor amount of PFAS mass remains under the Containment Cell in the FTG source area. PFAS concentrations reported in source area soil are summarised Table 9.2.

Table 9.2 PFAS concentrations in soil

Source area	Data source	Max. PFOS (mg/kg)	Max. PFOA (mg/kg)	Max. PFOS+PFHxS (mg/kg)	Max. Sum of PFAS (mg/kg)	No. samples tested	Exceeding applicable criteria	TA opinion
FTG & South Creek wetlands	Golder 2023 – Remaining in FTG (outside of containment cell)	1.2	0.0522	1.21	1.22	214	Yes	The management and mitigation measures implemented in this source area (i.e., encapsulation) did not affect the concentrations of PFAS in the soil and concrete, other than some mixing and dilution. The encapsulation materially decreased the mass discharge from this source area by limiting the potential generation of leachate and removed elevated concentrations from surface soil to protect base workers and trainees.
Fire Station & Ornamental Lake	Aurecon 2018	1.10	0.003	1.12	1.15	18	Yes	Some soil was removed as part of stormwater infrastructure upgrades, where the Ornamental Pond underwent modifications. The soil excavated as part of these works and was stockpiled within the footprint of the proposed Containment Cell (Aurecon 2021). Therefore, concentrations and mass discharge from this source area may have reduced.
Former STP	Aurecon 2018	0.016	0.008	0.171	0.050	8	No	No management or mitigation measures with respect to soil concentration were implemented. Therefore, concentrations and mass discharge from this source area remain unchanged.
Sullage pit, minor primary and secondary sources	Aurecon 2018	0.039	<0.001	0.039	0.22	52	Yes	No management or mitigation measures with respect to soil concentration were implemented. Therefore, concentrations and mass discharge from this source area remain unchanged.

Notes:

mg/kg – milligrams per kilogram

Minor primary and secondary sources: sports field, bushfire zone, closed landfills, stormwater drains/off-Site residential sources, storage tank areas, coal loading area, water filter wash-down area and UST and ASTs, Communications School, former dry-cleaning facility, powerhouse, on-Site residential sources.

9.2.4 Surface water

9.2.4.1 Concentration

PFAS concentrations in surface water have been monitored by Defence's consultants since 2017 under the Site OMP. The historical data provides important information on contaminant variability over time, which can be compared to post-cleanup levels in surface water bodies. The existing data indicate fluctuating concentrations, likely in response to seasonal effects and variability of rain events. The highest concentrations are associated with samples from close proximity to known sources, with lower concentrations at more distant locations, including those along the southeast boundary of the Base. The data do not suggest an increasing trend in concentration at any location. It is also unlikely that concentrations will exceed the maximum values seen in the OMP data as this would require significant increases in release of PFAS from source areas. Such a scenario is unlikely as the primary sources have been removed (i.e. the use of AFFF) and residual sources represent systems with ever-depleting and finite contaminant mass.

No direct management and mitigation measures were undertaken to reduce concentrations of PFAS in the surface water pathway. As such, the concentrations in the surface water are not anticipated to materially reduce in the short term until the decrease in source mass discharge from the FTG source area cleanup works is reported in the surface water concentrations measured during the OMP.

At the time of this report, no material changes in surface water PFAS concentrations could be ascertained as a result of the management and mitigation measures undertaken with any defensible level of confidence.

The most recent surface water data (i.e. Feb-April 2024) was reported in Stantec 2024, along with data collected over the OMP (beginning in 2017). Table 9.3 summarises the average PFAS concentrations pre-cleanup (2017 – Jan 2021) and post-cleanup (Jan 2021 – April 2024) and criteria exceedances.

The bioretention basins constructed in 2020 will act as a sink for PFAS, capturing mass in sediment. This will reduce the mass flux from this pathway.

Table 9.3 PFAS concentrations in surface water 2017 – 2024 (Stantec 2024)

Source area	Monitoring locations	Ave. PFOS (µg/L) pre-cleanup	Ave. PFOS (µg/L) post-cleanup	Ave. PFOA (µg/L) pre-cleanup	Ave. PFOA (µg/L) post-cleanup	Ave. PFOS+PFHxS (µg/L) pre- cleanup	Ave. PFOS+PFHxS (µg/L) post-cleanup	Ave. Sum of PFAS (µg/L) pre-cleanup	Ave. Sum of PFAS (µg/L) post-cleanup	No. samples tested pre-cleanup	No. samples tested post-cleanup	Exceeding applicable criteria pre-cleanup	Exceeding applicable criteria post-cleanup	TA's opinion
Hanns Inlet	SW004 SW077	1.621	1.347	0.361	0.318	4.484	3.937	6.772	5.813	7	39	Yes	Yes	No management or mitigation measures with respect to PFAS concentrations in surface water were implemented. Therefore, PFAS concentration changes are not likely to be related to management and mitigation measures in the source areas in the short term. Further long-term monitoring data over the medium to long-term will be required to demonstrate a material change in PFAS concentrations in surface water. The limitations (primarily variance over time) of data results restricts the ability to demonstrate a trend in an acceptable statistical confidence. The lack of a clear trend in PFAS concentrations was not considered a material data gap given the low risks and limited impacts to Environmental Values.
FTG & South Creek wetlands	SW027 SW029	2.332	0.181	0.060	0.009	2.610	0.241	4.245	0.357	11	51	Yes	Yes	
Former STP	SW023 SW079	0.003	0.026	0.000	0.001	0.003	0.036	0.000	0.076	4	33	No	Yes	
Drainage channels flowing onto Site	SW021 SW080	0.043	0.020	0.010	0.001	0.120	0.037	0.136	0.045	7	33	Yes	Yes	

Notes:

µg/L – micrograms per litre

Hanns Inlet includes: fire station & ornamental lake, sullage pit, closed swimming pool landfill.

9.2.4.2 Mass flux and mass discharge

No mass flux assessment was conducted before management and mitigation measures were implemented. Therefore, no baseline data was available before commencing cleanup works.

Mass flux assessments associated with surface water post-commencement of cleanup works, were reported in the following documents and summarised in the sections below:

- Aurecon (2023) HMAS Cerberus PFAS Mass Flux Study, Mass Flux Interpretive Report, dated March 2023 (Aurecon 2023).
- Stantec (2024) Addendum to Mass Flux Interpretive Report, dated June 2024 (Stantec 2024).

The Aurecon (2023) study sought to assess surface water mass flux utilising nine sampling locations at strategic points across the Base. The assessment involved collection of surface water elevation data using automated pressure loggers and manual gauging. This information was to be combined with rainfall data, tidal data and PFAS concentrations to assess mass flux in the surface water pathway. PFAS sampling was conducted at the nine sampling locations over two sampling events in November 2021 and January-February 2022. First-flush stormwater samples were also recovered from selected sample locations during both sampling events.

The stream elevation data was to be used to develop rating curves which correlate water surface elevations with discharge rates. Analysis of the data, however, indicated only weak relationships between elevation and flow which led to the development of mass flux estimates with low confidence. Hence the data could not be relied on to assess mass flux in the surface water pathway.

The Stantec (2024) study was commissioned to address the shortcomings of the Aurecon study. The objectives of the Stantec study were to estimate the mass of PFAS moving on and off the Site by the surface water (not groundwater) pathway and to find, if possible, a relationship between stream flow and PFAS concentrations.

Assessing mass flux of PFAS moving on and off the Site by the surface water pathway was based on combining the surface water flow rate with corresponding PFAS concentration and then scaling up this instantaneous data to represent longer timeframes i.e. days and years. Stantec collected data over a range of flow rates and grouped the flow data and PFAS concentrations to assess mass flux over the longer timeframes.

Stantec utilised water levels and continuous flow measurements over a period from December 2023 to April 2024 at eight locations – five non-tidally influenced and three exhibiting tidal influence. PFAS was sampled on five occasions during this period. Table 9.4 presents the mass discharge estimates calculated using the mass flux data.

Table 9.4 Mass discharge estimates undertaken from December 2023 to April 2024 (Stantec 2024)

Location	Details	Type	Mass discharge PFOS+PFHxS (g/y)
SW004	Closed Swimming Pool Landfill	Drainage outflow – stormwater drain (non-tidal)	0.003
SW021	East Creek on Disney Street	Inflow baseline -concrete culvert (non-tidal)	0.87
SW023	West Creek on South Beach Road	Inflow baseline – concrete pipe (non-tidal)	0.023
SW027	South Creek downgradient from Closed Rifle Range Road Landfill	Tidal creek downgradient of source areas (Tidal)	49
SW029	North corner of Closed Rifle Range Road Landfill	Drainage outflow – concrete channel (non-tidal)	2.5
SW077	Fire Station/Ornamental Lake	Drainage outflow - concrete pipe (non-tidal)	5.2
SW079	West Creek downgradient from former sewage treatment plant	Creeks downgradient of source areas (Tidal)	9.9
SW080	East Creek near Cook Road	Tidal creek downgradient of source areas (Tidal)	64

The Aurecon and Stantec studies indicated the greatest PFAS mass leaving the Site in surface water was via the main discharge points flowing into Hanns Inlet, i.e. SW027, SW079 and SW080, located in the South Creek, West Creek and East Creek, respectively.

9.2.5 Groundwater

9.2.5.1 Concentration

PFAS concentrations in groundwater have been monitored by Defence's consultants since 2016 under the OMP. The historical data provides important information on contaminant variability over time. The existing data indicate fluctuating concentrations, likely in response to seasonal effects and, in some cases, tidal effects. The highest concentrations are associated with samples from close proximity to known sources, with lower concentrations at more distant locations. The data tends to indicate mainly stable concentrations with values fluctuating within an upper and lower historical bound. As with surface water, the primary sources of PFAS (AFFF use) have been removed and it is expected that the residual mass of PFAS in sources and pathways will decline with time. Consequently, significant increases above the historical maximum concentrations are considered unlikely.

No direct management or mitigation measures were undertaken to address PFAS concentrations in groundwater. Consequently, short-term changes in groundwater concentrations are not expected until the reduced mass flux and consequent decline in mass discharge from the cleaned up FTG source area is reflected in ongoing monitoring data. This type of response lag is typical in groundwater systems due to the relatively low velocity of groundwater movement, which can result in considerable latency in response to cleanup actions in source zones that are implemented over a short time span.

At the time of this report, no significant changes in groundwater PFAS concentrations due to management and mitigation measures could be confirmed. No post-management groundwater PFAS concentration data from the FTG and other source areas is available at the time of this report.

Short-term changes in groundwater PFAS concentrations are unlikely to be linked to these measures. Long-term monitoring will be necessary to demonstrate any material changes. The lack of data showing a clear change (declining trend) in PFAS concentrations is not considered a significant data gap due to the low risks and limited environmental impacts.

9.2.5.2 Mass flux and mass discharge

Mass flux assessments associated with groundwater post-cleanup, were reported in Aurecon (2023) HMAS Cerberus PFAS Mass Flux Study, Mass Flux Interpretive Report, dated March 2023 (Aurecon 2023).

Assessing mass flux in groundwater requires a number of data inputs including hydraulic gradients, hydraulic conductivity and permeability, groundwater flow directions and contaminant concentrations, as well as climatic information (notably rainfall) and tidal impacts. The Aurecon 2023 groundwater mass flux study involved the installation of an additional 10 groundwater monitoring wells to enhance the well network.

Gauging of SWLs involved both manual gauging with an interface probe and continuous monitoring using automated data loggers at nine locations. The data provided an understanding of groundwater flow and gradients – both lateral and vertical.

Slug testing was conducted on a number of wells to assess hydraulic conductivities of the aquifer.

The continuous monitoring results were compared to rainfall data and indicated a correlation between rainfall and SWLs in the shallower wells. It also identified a tidal forcing in a location close to Hanns Inlet. The tidal response did not extend significant distances inland (in the order of 100-150 m).

Sampling of the well network allowed for the development of a plume map which is reproduced as Figure 9.1. This figure shows the highest groundwater concentrations in the vicinity of the FTG source area that was subject to management and mitigation measures. These measures are expected to decrease the mass discharge from this source area into the groundwater system, which should result in an overall lowering of PFAS mass flux in the medium to long term.

Figure 9.1 Sum of PFAS – interpolated above 0.1 µg/L isolevel (Aurecon 2023)

The mapping and other inputs allowed for the assessment of PFAS mass in the groundwater which was calculated at approximately 4.3 kg.

Aurecon assessed the mass flux using a transect approach. Eight transects were assessed to calculate mass flux across key source-pathway linkages (Figure 9.2). Details of each transect and the calculated mass flux are provided in Table 9.5.

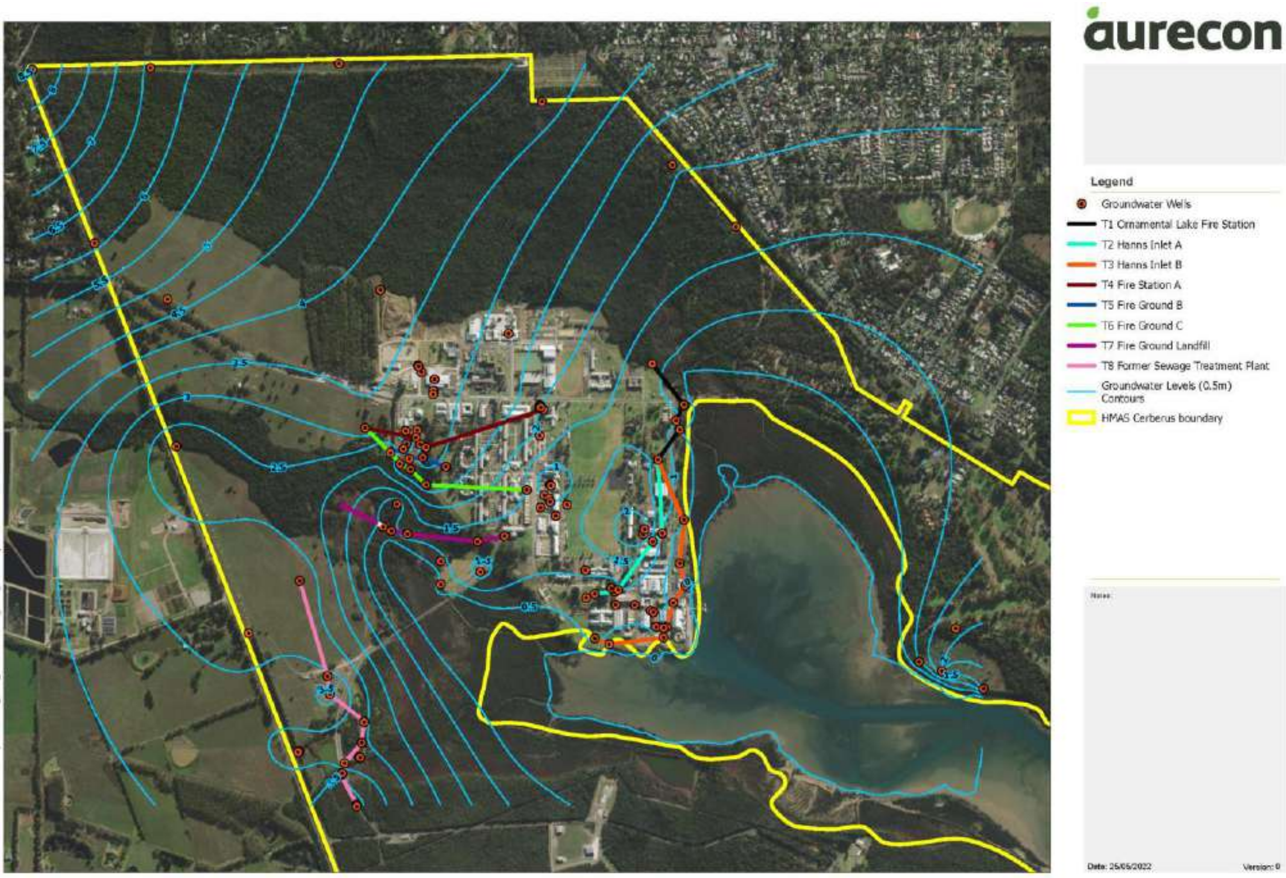


Figure 9.2 Groundwater flow contours and groundwater well transects (Aurecon 2023)

Table 9.5 Transect and mass flux estimates (2021 snapshot) (Aurecon 2023)

Transect	Area	Notes	Sum of PFAS flux (g/d/m^{23})
T1	Ornamental Lake Fire Station	Discharging off-base towards Hanns Inlet.	0.0014
T2	Hanns Inlet SE boundary A (upgradient)	Assessing PFAS mass flux from diffuse sources in the central portion of the Base. Does not directly contribute to off-Base mass flux (upgradient of T3).	0.0088
T3	Hanns Inlet SE boundary B (downgradient)	Discharging off-Base towards Hanns Inlet.	0.0004
T4	FTG A	Assessing PFAS mass flux from the FTG. Does not directly contribute to off-Base mass flux (upgradient of T5, T6, and T7).	0.197
T5	FTG B	Assessing PFAS mass flux from the FTG. Does not directly contribute to off-Base mass flux (upgradient of T6, and T7).	0.0852
T6	FTG C	Assessing PFAS mass flux from the FTG. Does not directly contribute to off-Base mass flux (upgradient of T7).	0.171
T7	FTG Landfill	Discharging off-Base towards South Creek.	0.005
T8	Former STP	Discharging off-Base towards West Creek and Hanns Inlet.	0.0009
T1+T3+T7+T8	Offsite discharge transects	Total mass from transects discharging off-Site.	0.0077

Time-based mass flux estimates were also conducted on T5 to assess the impact of cleanup works at the FTG. The assessment included data from previous years' groundwater sampling, from 2016 to 2020. The data indicated a range from 0.029 g/d (2016) to 0.234 g/d (2018) with an increasing trend between 2016 and 2018 and decreasing trend subsequently.

Based on the data presented, the mass flux estimates indicated approximately 0.0028 kg per year discharging from the Base via groundwater.

Given the large range of estimated mass flux in T5 (around an order of magnitude) prior to undertaking management and mitigation measures suggests that a body of monitoring data collected over a number of years will be required before being in a position to assess the effectiveness of the FTG cleanup activities on reducing mass flux.

9.2.6 Air

No assessment of PFAS in air has been conducted. The PFAS transport mechanisms associated with the air pathway are not considered a potential exposure pathway to receptors. Therefore, there is no on-Site source above background concentrations.

9.3 Receptors

The TA has completed an assessment of receptors following management and mitigation measures including cleanup at the FTG which is summarised in Table 9.6 and Table 9.7.

Table 9.6 Human receptors assessment

Human receptor	Complete pathway	Level of risk	TA's opinion
On-Site			
Base Workers and Trainees	Yes	Low and acceptable	Does not require further consideration.
Intrusive construction workers	Yes	Low and acceptable	Site management required to prevent excavation of on-Site encapsulation (refer to Section 8.7).
Site visitors	Yes (Likely)	Low and acceptable	Does not require further consideration.
Childcare attendees	No	Low and acceptable	Does not require further consideration.
Residents	No	Low and acceptable	Does not require further consideration.
Off-Site			
Commercial producers of agricultural products	No	Not assessed	Does not require further consideration.
Commercial producers of aquaculture products	No	Low and acceptable	Does not require further consideration.
Western Port Bay fish consumers	Yes (Unlikely)	Low and acceptable	Does not require further consideration. No fishing or aquaculture is permitted in Hanns Inlet and Naval Water.
Wildlife or game consumers	No	Low and acceptable	Does not require further consideration.

Table 9.7 Ecological receptor assessment

Ecological receptor	Complete pathway	Level of risk	TA's opinion
On-Site terrestrial flora			
Grass, trees and other vegetation	Yes (Likely)	Low and acceptable	Does not require further consideration.
On-Site terrestrial fauna			
Mammals, including rabbits, kangaroos and possums	Yes (Likely)	Low and acceptable	Does not require further consideration.
Birds, migratory and local	Yes (Likely)	Low and acceptable	Does not require further consideration.
Reptiles and insects	Yes (Likely)	Low and acceptable	Does not require further consideration.
Grass, trees and other vegetation	Yes (Likely)	Low and acceptable	Does not require further consideration.
Semi-aquatic biota, including crabs and worms	Yes (Likely)	Low and acceptable	Does not require further consideration.
On-Site aquatic fauna			
Fish, including flathead, whiting, mullet, Australian salmon, toad fish and trevally	Yes (Likely)	Low and acceptable	Does not require further consideration.

Ecological receptor	Complete pathway	Level of risk	TA's opinion
Fiddler rays and gummy sharks	Yes (Likely)	Low and acceptable	Does not require further consideration.
Pipis, oysters and crustaceans	Yes (Likely)	Low and acceptable	Does not require further consideration.
Benthic detritivores	Yes (Likely)	Low and acceptable	Does not require further consideration.
Off-Site terrestrial flora			
Grass, trees and other vegetation	No	Low and acceptable	Does not require further consideration.
Off-Site terrestrial fauna			
Mammals, including horses, cows, rabbits and possums	No	Not assessed	Does not require further consideration.
Birds, migratory and local	Yes (Possible)	Low and acceptable	Does not require further consideration.
Off-Site aquatic fauna			
Fish, including flathead, whiting, mullet, Australian salmon, toad fish and trevally	Yes (Unlikely)	Low and acceptable	Does not require further consideration.
Fiddler rays and gummy sharks	Yes (Unlikely)	Low and acceptable	Does not require further consideration.
Pipis, oysters and crustaceans	Yes (Unlikely)	Low and acceptable	Does not require further consideration.
Benthic detritivores	Yes (Unlikely)	Low and acceptable	Does not require further consideration.

All risks to receptors were considered to be low and acceptable following implementation of the management and mitigation measures as part of the opportunistic cleanup of the FTG source area. As a result, the implemented management and mitigation measures have reinforced the absence of any risk driver for completion of any active management and mitigation measures to address PFAS impacts at the FTG (RAN SSSS). The cleanup of the FTG was therefore undertaken on a voluntary basis as part of the Base redevelopment, rather than be in response to risk drivers.

9.4 Risk to Environmental Values after cleanup

An assessment of Environmental Values has been undertaken by the TA, post-cleanup. It is the opinion of the TA that risks to all relevant Environmental Values that were assessed as potentially precluded with further assessment warranted prior to cleanup (refer to Table 4.8) are now low and acceptable. Therefore, no further active management and mitigation measures are currently required at the Site. Ongoing monitoring should continue to confirm that risks to Environmental Values remain low and acceptable.

TA's Opinion on Site condition after completion of active management and mitigation measures

The Site's geomorphological setting was considered to be adequately characterised to assess changes in risks to human health and the environment after implementing management and mitigation measures. Those aspects with respect to PFAS mass that were insufficiently characterised were not considered to adversely affect the TA's ability to assess the Site condition as:

– The PFAS mass within each source area was not specifically characterised. This data gap was not considered to materially affect the TA's ability to form an opinion on cleanup due to:
  - Risks to and impacts on Environmental Values being low and acceptable.
  - The main source mass being characterised in the FTG, which was the source area subject to active management and mitigation measures.
  - Some opportunistic cleanup of minor source areas such as the Ornamental Pond being undertaken.

– The source mass discharge from each source area was not specifically characterised. This data gap was not considered to materially affect the TA's ability to form an opinion on cleanup due to:
  - Risks to and impacts on Environmental Values being low and acceptable.
  - The main source mass being characterised in the FTG, which was the source area subject to active management and mitigation measures.
  - Some opportunistic cleanup in the Ornamental Pond area and placing the secondary source material into the Containment Cell at the FTG.

– No assessment of mass flux from the source areas and total mass discharge from the Base was conducted before implementing management and mitigation measures, including encapsulation of PFAS impacted soils in the FTG. As such no baseline information to assess the effectiveness of the management and mitigation measures on mass flux is available. This data gap was not considered to materially affect the TA's ability to provide an opinion on cleanup due to:
  - The risks to and impacts on Environmental Values were low and acceptable.

The assessment of risk to Environmental Values following implementation of the management and mitigation measures (encapsulation of PFAS impacted concrete and soil from the FTG) was considered to have been adequately undertaken by the remediation contractor (RC). This allowed the TA to provide an opinion in regard to cleanup, based on the following lines of evidence:

– Risks to all on-Site and off-Site receptors with chronic and long-term exposure were found to be low and acceptable.

– Risks to on-Site receptors with short-term direct exposure (primarily those in direct contact with the soils (i.e. Base workers, Defence trainees and construction/maintenance workers) can be readily managed and mitigated by simple and easily implementable occupational health and safety measures.

Based on these considerations, the TA concludes that the Site conditions after implementation of the management and mitigation measures as part to the Site cleanup activities were sufficiently characterised to support an assessment with respect to the impacts of residual PFAS on Environmental Values.

10. Final site condition after cleanup

In April 2018, a major base redevelopment was implemented at the Site that included the decommissioning and demolition of the School of Ship Safety and Survivability (SSSS) in the area of the FTG PFAS source area. Clean up of the PFAS impacted soils in the FTG source area occurred opportunistically as part of this redevelopment, to address elevated risks and enhance Defence capability rather than to respond to any unacceptable risks to receptors and impacts to Environmental Values.

Therefore, the driver for implementation of the management and mitigation measures was opportunistic, rather than due to unacceptable risk to receptors and impacts to Environmental Values.

The TA critically and independently reviewed all data produced by Defence's LCs and RC that characterised PFAS impacts in various media and validated clean-up activities and source mass encapsulation. The TA assessed the limited number of on-Site receptors identified to be at a potentially elevated risk in regard to PFAS exposure, post cleanup. The TA concluded that there was no material degradation of Environmental Values on-Site and off-Site and no strong drivers for undertaking any additional active management and mitigation

10.1 PFAS sources

The TA considered that sufficient information was compiled on the historical uses, storage and movement of AFFF, drainage flows and soil /sediment movement to identify where PFAS impacts to soil, surface water and groundwater have occurred. As a result, the TA is comfortable that sources of PFAS mass discharge into the environment at the Base have been identified and sufficiently characterised to inform any management and mitigation measures to address PFAS impacts. The key source areas remaining after implementation of management and mitigation measures are summarised in Table 9.2.

The primary management and mitigation measure implemented included the encapsulation of around 70% of the PFAS impacted soils in the FTG source area and limiting the infiltration and leachate generation from the remaining PFAS impacted soils in that source area. The opinion of the TA with respect to the adequacy of the management and mitigation measures for each key source area are as follows:

– **FTG & South Creek wetlands:** The TA considers that the management and mitigation measures (encapsulation) in this source area were reasonable and achieved reduction in source mass discharge from this source based on the following considerations:
  - The placement of a clean soil capping layer over the PFAS impacted soil breaks the SPR linkage and removes exposure for Defence personnel and construction/maintenance workers that frequent the area.
  - The clean soil capping layer also interrupts the SPR linkage by addressing exposure of terrestrial flora and fauna.
  - The soils with the highest PFAS concentrations are encapsulated within the Containment Cell, preventing PFAS source mass discharge to the environment. This results in decreases to the mass flux contribution to the surface and groundwater migration pathway by which PFAS leaves the Site and discharges into the environment.
  - The residual PFAS impacts in soils that remain outside of the Containment Cell have relatively lower concentration and reside below the cell, which has resulted in a reduced potential for source mass discharge due to reduced infiltration of rainfall into this soil that could generate leachate.
  - The risks to receptors in this source area remain low and acceptable post-cleanup, with the cleanup actions decreasing exposure to on-Site receptors, as well as mass discharge, further decreasing risk.
  - Environmental Values of the area remain unimpacted post cleanup, with cleanup actions decreasing mass discharge to the environment providing further protection of Environmental Values.

– **Fire Station & Ornamental Lake:** The TA considers that the decision not to undertake management and mitigation measures in this source area were reasonable at this time based on the following considerations:
  - The soil concentrations, while above the adopted screening criteria, are relatively low and any risks to Defence personnel and maintenance/construction workers can be managed through the adoption of simple, effective and proven OHS measures.
  - The PFAS impacted soils do not appear to represent a material source of mass discharge into the environment, which is reflected in the relatively low concentrations in the surface water and groundwater pathway near this source.
  - The risks to receptors in this source area are considered low and acceptable.
  - Environmental Values of the area are not materially degraded.
  - The facility represents a critical Defence capability that needs to be maintained to allow the Site to operate.

– **Former STP:** The TA considers that the decision not to undertake management and mitigation measures in this source area were reasonable at this time based on the following considerations:
  - The soil concentrations, while above the adopted screening criteria are relatively low and would not represent a material source of mass discharge into the environment, which is reflected in the relatively low concentrations in the surface water and groundwater pathway near this source.
  - The risks to receptors in this source area are considered low and acceptable.
  - Environmental Values of the area are not materially degraded.
  - The area is not frequented by Defence personnel and maintenance workers.

– **Sullage pit, minor primary and secondary sources:** The TA considers that the decision not to undertake management and mitigation measures in these source areas was reasonable at this time based on the following considerations:
  - The concentrations of PFAS in soils in this area were below the adopted environmental and human health protection screening levels. Therefore, ongoing use of the areas by Defence personnel and maintenance/construction workers can continue with no requirements for any OHS /personal protection measures.
  - The concentrations are relatively low and would not represent a material source of mass discharge into the environment, which is reflected in the relatively low concentrations in the surface water and groundwater pathway near this source.
  - The risks to receptors in this source area are considered low and acceptable.
  - Environmental Values of the area are not materially degraded.

10.2 PFAS transportation pathways

The TA considered that sufficient information was compiled on the drainage infrastructure, hydrology and hydrogeology to identify the primary pathways by which dissolved phase PFAS can impact surface water and groundwater. As a result, the TA is comfortable that the pathways by which PFAS mass moves from the source areas towards the boundary and discharges into the surrounding environment are sufficiently characterised. The surface water (drainage infrastructure, East, West and South Creeks) provides the primary pathway for PFAS total mass discharge off-Site. Groundwater is a lesser pathway and much of the PFAS mass in groundwater enters the surface water pathway on-Site. Off-Site, the PFAS mass flux by the groundwater pathway is likely to be limited.

No active management and mitigation measures with respect to the surface water and groundwater PFAS pathways was undertaken. The opinion of the TA with respect to the key pathways at the time of this report are:

– **Surface water pathway:** The TA considers that the decision not to undertake active management and mitigation measures with respect to this pathway was reasonable due to:
  - While PFAS concentrations in this pathway exceed one or more of the adopted screening criteria, the mass flux associated with this pathway has not resulted in an elevated risk to receptors.
  - The relevant Environmental Values into which the mass flux in this pathway flows are not impacted to an extent where the values are materially degraded.

– **Groundwater pathway:** The TA considers that the decision not to undertake active management and mitigation measures with respect to this pathway was reasonable due to:
  - Groundwater being a minor pathway, with most of the mass flux entering the surface water pathway within the Site boundaries.
  - While PFAS concentrations in this pathway exceed one or more of the adopted screening criteria, the groundwater is not beneficially utilised within the identified zone of PFAS impact.
  - The mass flux associated with this pathway has not resulted in an elevated risk to receptors.
  - The relevant Environmental Values into which the mass flux in this pathway flows are not impacted to an extent where the values are materially degraded.

On that basis, the decision to limit the active management and mitigation measures to reduce the source mass discharge from the FTG source area to these pathways was reasonable as the Site did not present any unacceptable risks to any receptors and there was no material degradation of Environmental Values.

10.3 Receptors

The TA considered that sufficient information was compiled to identify and characterise the key receptors that may be exposed to PFAS impacted media when a complete SPR linkage has been identified.

Table 9.6 and Table 9.7 demonstrate that after cleanup, there are no elevated risks to receptors at the time of this report. Therefore, there does not appear to be a risk-based driver to undertake any further active management and mitigation measures to reduce risk to receptors. The TA considers that the decision not to undertake any active management and mitigation measures with respect to the receptors for which a complete SPR linkage existed was reasonable.

10.4 Mass flux

The TA considered that sufficient information was collected to characterise the primary pathways by which PFAS impacted media moves away from the source areas to support an assessment of mass flux with an adequate level of confidence in the context of the risk profile and impacts to Environmental Values.

Given the low and acceptable risks to receptors and no material degradation to Environmental Values, the TA considers it reasonable to limit active management and mitigation to the FTG source area, thereby reducing mass discharge and contribution to mass flux.

10.5 Mass discharge

The TA considered that sufficient information was collected to characterise the total mass discharge from the Site, based on the sum of pathway mass flux and source mass discharge calculations.

The decision to limit active management and mitigation measures to the FTG source area, in turn reducing the mass flux contribution from this area to the total mass discharge, was deemed reasonable by the TA.

10.6 Risks to human health and the environment

Based on the available information and risk assessment outcomes, the TA deems the residual PFAS impacts to human health and the environment to be low and acceptable at the time of this report (refer to Table 9.6 and Table 9.7). Therefore, the TA believes that ongoing monitoring, administrative controls and contingency actions for the residual PFAS impacts will be sufficient to ensure the uninterrupted operation of Defence on the Site within the anticipated variance in environmental conditions.

11. PMAP action review

PMAP actions were developed to address Defence's management of risks, through avoiding or minimising exposure to PFAS contamination from Defence property to human health and ecological receptors. The actions prioritise a combination of measures:

- Implementing practicable solutions to prevent or minimise the migration of PFAS beyond the Defence property boundary through:
  - Reducing the source mass of PFAS contamination.
  - Blocking or diverting the migration pathway of the contamination from the source to receptors.
- Working to protect the community from exposure during the implementation of management actions to address PFAS contamination at source areas and/or in migration pathways.

Table 11.1 outlines the PMAP actions and how they have been addressed through the works completed to date.

Table 11.1 PMAP actions and responses

PMAP action	Status of action & TA's opinion on closure
Continue the use of PFAS-free training foam (such as Solberg) for all training exercises within the Fire Training Ground – already implemented.	The TA is of the understanding that the new fire training facility, constructed as part of the Base redevelopment, minimises foam discharge and utilises foam in conformance with this action.
Undertake source removal and/or treatment of residual PFAS within the Fire Training Ground, as part of the Base Redevelopment Project. The current design solution incorporates the consolidation of impacted materials within a containment cell (option 1c - on-site engineered repository) which will be designed in general accordance with the Defence Per- And Poly-Fluoroalkyl Substances (PFAS) – Engineered Stockpile Facility Performance Specification.	The TA confirms that this cleanup action was implemented, and the final Containment Cell was completed in accordance with this PMAP action as set out in Section 8 of this report. The TA considers that no further active cleanup actions are required with respect to this element of the PMAP. Any ongoing requirement to maintain and monitor the integrity of the Containment Cell can be accomplished as part of routine monitoring and management of the Site.
Manage any residual soil and sediment impacts encountered during the Base Redevelopment Project in accordance with the Defence PFAS Framework - Construction and Maintenance projects. It is noted that this will entail the testing and treatment of groundwater and surface water from dewatering trenches and open excavations, and the containment or sensitive reuse of soils and demolition waste.	The TA is of the understanding that the residual PFAS impacted soil and sediments, surface water and groundwater encountered during Base redevelopment works were dealt with in accordance with this action. Section 8 of this report provides further information in this regard and sets out the information available to the TA with respect to this PMAP action.
Mitigate risk to on-Site intrusive/maintenance/construction workers through the continuing imposition of administrative control measures, most of which are already in place, from both Defence's and the professional contractor's perspectives.	The TA is of the understanding that this PMAP action has been implemented and details of the information available to the TA in this regard are presented in Section 7.7 of this report.
Mitigate risks associated with precluded beneficial uses, such as stock watering or irrigation, through administrative control measures, such as banning of groundwater extraction except for monitoring or temporary construction dewatering.	The TA is of the understanding that this PMAP action has been implemented through implementation of a management plan and includes restrictions to on-Site use of groundwater through appropriate administrative controls with respect to the impacted beneficial uses.
Implementation of the OMP to assess the effectiveness of the cessation of AFFF and to assess temporal trends in residual PFAS concentrations in surface water and groundwater.	The TA can confirm that an OMP has been implemented that includes continued groundwater and surface water monitoring requirements to assess PFAS mass discharge to the environment.

12. Conclusion

Based on the TA's critical and independent review of the available information presented by Defence's consultants, the following conclusions can be drawn:

- The Site has phased out use of legacy AFFF products that contain PFAS, which has removed the primary source of PFAS impacts on Environmental Values.
- Sufficient information on the historical use of legacy AFFF products that contained PFAS was collected to identify:
  - The source areas where the most significant impacts by PFAS on media (primarily soil) are likely to occur and from which mass discharge to pathways occurs.
  - The pathways by which PFAS mass moves within and off-Base and discharges into the wider environment.
  - The receptors that may be exposed to PFAS.
- Sufficient representative, robust and defensible data was collected to characterise the nature and extent of PFAS source areas, mass flux and mass discharge pathways and receptors that are exposed to assess risks to and impacts on Environmental Values.
- A sufficiently robust assessment of SPR linkages was completed to identify complete linkages that can inform the assessment of risk to human health and the environment.
- A sufficiently robust and defensible assessment of risks to human health and the environment posed by PFAS with respect to complete SPR linkages was undertaken. The outcomes of the risk assessment prior to undertaking any management and mitigation measures found that all risks were low and acceptable, except for:
  - Defence personnel involved in training activities within PFAS source areas where impacts are near the surface.
  - Maintenance/construction workers involved in activities that interact with the soils and shallow groundwater within the source areas.

These risks can be adequately managed through implementation of simple, effective and proven personal protective measures that are economical and commensurate with the risk level, with no driver for implementation of further active management and mitigation measures.

- A sufficiently robust and defensible assessment of PFAS impact to Environmental Values was undertaken and indicated that no material impact on Environmental Values had occurred.
- The outcomes of the assessments completed at the Site found that in the context of the PFAS impacts across the Defence estate, this Site did not present an elevated risk and did not materially impact Environmental Values. Therefore, there was no driver to undertake active management and mitigation measures with respect to PFAS impacts on and off-Site.
- The Site was subject to a major upgrade and redevelopment program, including the FTG situated within the SSSS. The FTG was identified as a PFAS source area which contributed to mass discharge to the surface water and groundwater pathways. Given the major redevelopment works undertaken at the Base, the reasonable decision was made to take the opportunity to reduce the PFAS mass discharge by encapsulating the majority of the PFAS impacted concrete and soil in a containment cell.
- Following completion of the cleanup at the FTG and in the absence of any risk and impact to Environmental Values, no further active management and mitigation measures to further decrease source and pathway mass discharge were considered to be necessary at the Site at this stage. On that basis, the TA was of the opinion that the impacts associated with PFAS at the Base had been addressed within the context of PFAS impacts across the Site and can move from the active management and mitigation phase to a passive monitoring and contingency phase.
- All PMAP actions have been addressed and the PMAP can be transitioned to management under the Aftercare Management Plan for the containment cell, and ongoing monitoring under the OMP.

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