Australian Government
Department of Defence

Singleton Military Area

PFAS MANAGEMENT AREA PLAN

December 2021

ABOUT THIS DOCUMENT

This is the Defence PFAS Management Area Plan (PMAP) for the Singleton Military Area.

This PMAP sets out a plan for Defence to manage the elevated risks of PFAS contamination on and emanating from the Singleton Military Area, as identified in:

- the Detailed Site Investigation report of December 2019 (AECOM, 2019b)
- the Detailed Site Investigation Addendum report of January 2021 (AECOM, 2021a)
- the Human Health and Ecological Risk Assessment (HHERA) of January 2021 (AECOM, 2021b).

It also documents the options development and assessment process, and rationale for the proposed response actions to manage those risks.

This PMAP will be published on the Defence website and will be reviewed annually (or earlier where required) to account for changes in circumstances, including:

- progress in risk management and the effectiveness of specific response actions
- data from the Ongoing Monitoring Plan (OMP)
- changes of land use
- changes in legislation, strategy, policy and guidelines/standards
- outcomes of new research or development of management/remediation
- any other new information that has the potential to impact the outcomes of the PMAP.

EXECUTIVE SUMMARY

Purpose

The PFAS Management Area Plan (PMAP) for Singleton Military Area (SMA) is a roadmap detailing the management measures to address soil and water contamination concerns and potential risks resulting from per- and poly-fluoroalkyl substances (PFAS) on and from the SMA. This document sets out to describe the management actions undertaken to date and maps out future remedial and management actions required to mitigate identified unacceptable risk and/or significant PFAS source contribution.

The PMAP also documents the options development and assessment process, and the rationale for the proposed response actions to manage identified risks.

Background

The SMA is a large and important military base located at Range Road, Singleton, in the Hunter Valley region of New South Wales. The SMA is located approximately 3 km south-west of the Singleton township and covers an area of approximately 15,000 hectares. The SMA was established in 1939 and houses the Australian Army School of Infantry and Special Forces Training Centre.

The SMA is divided into the Lone Pine Barracks (the Cantonment) which is comprised of accommodation, maintenance and training facilities, and the Singleton Training Area (STA) which is comprised of a number of former and active ranges for weapons firing, vehicle training and explosives testing. Support activities undertaken primarily at the Cantonment include vehicle maintenance, storage and distribution of fuels and equipment wash-down and historically firefighting training. A fire station was operational at the Cantonment between 1963 and 1994. There are no known stores of Aqueous Film Forming Foam (AFFF) remaining at the SMA and firefighting training is not known to have occurred since the closure of the former fire station. Firefighting services when required for the SMA are now understood to be undertaken off-Base at the Fire and Rescue NSW Singleton station. Historical activities also included the burial of waste materials in shallow landfills across the Cantonment and the SMA.

PFAS, in general, are moderately to highly soluble and relatively mobile, and able to rapidly leach through soils or disperse in waterways, travelling long distances, as well as being able to permeate the surfaces of some solid matrices (e.g. concrete). PFAS, in particular perfluoroalkyl acids (PFAAs), are chemically and biologically stable, being resistant to breakdown and evaporation, as well as being environmentally persistent and bio-accumulative. PFAS has been found in some areas of the SMA and beyond the SMA, spread predominantly via surface water and the discharge of wastewater effluent from the off-Base Singleton Waste Water Treatment Plant (STP) into the nearby community and from surface water to groundwater through the alluvial soils of the Hunter River floodplain.

The Management Area

The term ‘Management Area’ in this PMAP is applied to two distinct areas:

1. On Site- Management Area: which includes the SMA
2. Off-Base Management Area: which includes private properties to the north west, north and north east of the SMA. Activities to be implemented in the Off-Base Management Area will be focussed on ongoing monitoring.

Environmental investigations undertaken by Defence have shown that the migration of PFAS from the SMA and the Singleton STP have and is continuing to impact surface water and possibly sediment within the Management Areas (off-Base).

Identified Risks

Potential risks have been identified for people who live off-Base within the broader Study / Investigation Area (as defined in the HHERA [AECOM, 2021b]), and who eat a large proportion of their diet sourced from:

- **Ingestion of home-grown red meat from sheep or cattle** that have consumed water containing detectable PFAS, or have grazed in areas irrigated or flooded with water containing detectable PFAS
- **Ingestion of home-grown milk from cows** that have consumed water containing detectable PFAS, or have grazed in areas irrigated or flooded with water containing detectable PFAS
- **Cumulative ingestion of home-grown red meat, of home-grown milk from cows from sheep or cattle** and of **eggs** from home-grown backyard poultry that have consumed water containing detectable PFAS, or have grazed / roamed in areas irrigated or flooded with water containing detectable PFAS.

Drinking groundwater may present a future risk to off-Base users of groundwater (it is not known to currently occur), should the land and water use change including groundwater extraction as a drinking water source occur near the SMA. It is stressed that that groundwater is not currently known to be used as a drinking water supply within the Study / Investigation Area[1] (as defined in the HHERA [AECOM, 2021b]). As drinking of groundwater is not currently known to occur it has not been considered in this PMAP, however, should the land use and/or groundwater use change in the future this risk may need to be addressed and the PMAP updated accordingly.

The ecological risk assessment (ERA as presented in AECOM [2012b]) concluded that based on the available data presented and consideration of the uncertainties identified, the outcomes of the ERA indicate that there is low to minimal potential for direct or indirect risks to ecological (aquatic and terrestrial) receptors from exposure to PFAS in the Study/Investigation Area. Thus, no site management measures are considered necessary to abate PFAS exposure to ecological receptors.

Management Options Analysis and Integrated Options Analysis

The management options analysis focusses on the PMAP source areas, evaluating their contribution and the key off-Base migration pathways. The management options analysis considered:

a) source area management
b) pathway management
c) receptor management.

Management / remediation options were considered for:

- sources of PFAS in soil, surface water and groundwater and their associated contribution (on-Base primary sources [Former Cantonment Fire Station, DNSDC, Dochra Airfield, the HLG and ALG] and secondary sources)
- migration pathways – on and off-Base pathways which facilitate migration of PFAS and potential exposure pathways (i.e. surface water and groundwater migration)
- off-Base receptors who are or maybe potentially exposed to PFAS.

[1] Note that the Management Area as defined within this PMAP lies within the HHERA Investigation Area.

The integrated options analysis built on the management options analysis to identify the elevated risks that can be managed through implementation of the preferred risk management options. The collective analysis demonstrates how the preferred management options aim to concurrently and commensurately reduce multiple elevated risks and or improve the understanding of the significance of source contribution and mass flux. It is important to note that the implementation of risk management options will not immediately negate some risks (i.e. following implementation of source or pathway management options, it is likely to take some time until off-Base PFAS concentrations reduce to acceptable levels).

Management Actions

In managing the risks associated with PFAS contamination on the broader Defence estate, Defence currently prioritises two sets of actions:

- implementing practicable solutions to prevent or minimise the migration of PFAS beyond the subject Base through either:
    - reducing the mass of the PFAS contamination at the source, and/or
    - preventing or minimising the migration of significant PFAS contamination from the source to people or other sensitive receptors, and
- working to protect the community's exposure to PFAS while management actions addressing source areas and/or migration pathways are underway.

The outcomes of the analysis for planned PMAP response actions at priority PFAS source areas identified at the SMA are summarised below.

1. **Data Gap Investigation at the Former Cantonment Fire Station**. The data gap investigation should consider the use of rainfall simulation and the installation of lysimeters to estimate the quantum and significance of contribution of this source to PFAS concentrations in surface water at the Base boundary.
2. **Review the works planned at the DNSDC as part of the SMA Mid Term Refresh**. Part of the DNSDC compound is planned to be demolished during 2021 as part of the SMA Mid Term Refresh. As such, it is prudent this program of works is better understood before any remedial activities are planned. Appropriate guidance should be provided to the SMA Mid Term Refresh project on the appropriate management of PFAS.
3. **Undertake a Mass Flux Study**. A mass flux study should be undertaken to understand the on-going contribution of PFAS from the SMA and its source areas to the environment via partitioning of PFAS from residual soil mass to water via surface water drainage and groundwater.
4. **Implement the On-going Monitoring Plan (OMP)** to monitor changes in PFAS concentrations within the Management Area, in groundwater, in wastewater discharge and in surface water bodies that ultimately drain to the Hunter River and regional groundwater.
5. **Work with NSW Government and other stakeholders to evaluate the significance of current data gaps**. This assessment would focus on groundwater impacts above the health-based guidance values in the north eastern part of the Management Area as identified during the DSI Addendum (AECOM, 2021a) and understand the contribution of PFAS from the Singleton STP.

PMAP Review and Update

Ongoing implementation of the PMAP (including the OMP) will be subject to continuing annual review and update, to ensure documentation remains current and relevant, and reflects the results of the management actions and OMP (as described above and below) and advances in information and technology (based on ongoing technology performance assessment and review). Where changes to the PMAP and/or OMP occur, they will be communicated and discussed with the community and other stakeholders, including relevant local, NSW and Commonwealth government authorities.

Ongoing Monitoring Plan (OMP)

Ongoing monitoring will be performed in order to assess the performance of the current management systems and monitor changes in PFAS contaminant distribution.

The effectiveness of current management strategies / actions will be regularly assessed, and the program of forward works updated to achieve the most effective outcomes. Specific reviews and updates may be triggered in the event of monitoring indicating unexpected changes in PFAS distribution or concentrations, changes to legislation or guidance documents such as the PFAS National Environment Management Plan (NEMP, 2020), or availability of new remediation technologies.

Sampling campaigns will occur during the middle of the-year and at the end of year. Additional, monthly surface water sampling is stipulated for a minimum period of one year.

The OMP for the Management Area is included at **Attachment 1** of this PMAP and is to be made publicly available. It will also be shared with State and Commonwealth authorities.

Implementation

Potential timeframes for the implementation of identified response actions will vary between the short term (less than 12 months) and the long term (beyond 3 years) depending on the action. Implementation of response actions and proposed timeframes are detailed in Section 7.1.

Contents

GLOSSARY

ASS	Acid sulphate soils
Base	A defined physical locality or geographical area from which Defence-related activities, operations, training or force preparations are managed, conducted, commanded or controlled.
DSI	Detailed Site Investigation as identified in Section 1.5
DSI Addendum	Detailed Site Investigation Addendum
ERA	Ecological Risk Assessment
Extended implementation period	Period when PMAP response actions are required beyond the primary implementation period. These actions include ongoing: • monitoring, leachate management, and maintenance of stockpiles • monitoring of Management Area for PFAS • assessment of developments and technologies for application to stockpiled PFAS impacted soils and materials
Guideline value	Concentration of a contaminant above which further appropriate investigation and evaluation will be required
HEPA	Heads of EPA, a forum of State, Territory and Commonwealth environmental regulators, and publisher of the PFAS NEMP
HHERA	Human Health and Ecological Risk Assessment
HHRA	Human Health Risk Assessment
Management Area	The geographical area subject to Defence response actions as described in Section 1.5
Net environmental benefit (NEB)	The net impact of a contamination response action on the environmental health of the ecosystem/s within the Management Area (or an adjoining ecosystem) that is the target of the response action. An assessment of NEB involves an assessment of risk reduction of PFAS contamination, together with: a) impacts on: • ecosystem health • sensitive species • fate and transport of PFAS. b) planned mitigation actions for any negative impacts.
Off-Base	Off-Base (or other Defence property)
Ongoing Monitoring Plan (OMP)	The ongoing monitoring plan forming a part of this PMAP as set out in Section 5 and Attachment 1.
On-site	On-Base (or other Defence property)
PFAS NEMP	PFAS National Environmental Management Plan 2018 developed cooperatively between Australian jurisdictions or as revised from time to time.

Primary implementation period	The period for completion of PMAP response actions characterised as primary implementation response actions.
Primary source area	An original source of PFAS contamination, generally on-site, for example, a fire-fighting training ground
Project site	A defined site for construction and maintenance works within a Base
PSI	Preliminary Site Investigation
Public Works Committee (PWC)	Required to approve higher value public works (exceeding $15 million) and assess public works with a value of between $2 million and $15 million).
Remediation Action Plan (RAP)	Defines the purpose and objectives of the remediation, evaluates and determines the remediation options, and sets out performance measures.
Response actions	Actions identified as recommended or potential options to address potential risks
Response Management Strategy (RMS)	The Defence PFAS Response Management Strategy
Risk assessment(s)	The HHERA, HHRA and/or ERA described in Section 1.5
Secondary source area	An area containing elevated PFAS concentrations originally sourced from pathways from a Primary source area, and itself functioning as a source area
Site Selection Board	Approve the siting of semi-permanent and permanent structures, including the location of response actions and any supporting infrastructure.
Source area	An area within the Management Area that is, or has the potential to be, a source of contamination

Unless otherwise defined in this document, terms defined in the NEMP or the ASC NEPM have those meanings. In the event of conflict, definitions used in the NEMP are to be preferred.

1 INTRODUCTION

1.1 Purpose

This PFAS Management Area Plan (PMAP) provides a broad roadmap for response management by Defence of potential risks arising from per- and poly-fluoroalkyl substances (PFAS) contamination associated with the Singleton Military Area (SMA) and surrounding areas, in a manner that is consistent with the PFAS National Environmental Management Plan (NEMP [HEPA, 2020]). The location of the SMA is shown on Figure F1 (Appendix F).

Defence's management of the risks under the PMAP aims to avoid or minimise exposure to PFAS contamination from Defence property to human and ecological receptors. In doing so, Defence prioritises the following combination of measures:

1. Implementing practicable solutions to prevent or minimise the migration of PFAS beyond the Defence property boundary through:
    - Evaluating and / or reducing the mass of the PFAS contamination at an identified source(s), and/or
    - blocking or diverting the migration pathway of PFAS contamination between the source to a receptor.
2. Limiting the community from exposure while management actions addressing source areas and/or migration pathways are underway.

1.2 Application

This document will be used by Defence (including contractors) managing or carrying out the response actions set out in this PMAP.

This document may also be relevant for reference or aligning actions:

- By Defence environmental staff responsible for approving Environmental Clearance Certificates (ECCs) and any other similar approvals required for implementation of this PMAP
- By Defence (including contractors) carrying out construction and maintenance works on the Defence estate
- During the development and delivery phases of response actions, including by Site Selection Boards.

The NSW Environment Protection Authority (EPA) and other relevant State and Local agencies have been consulted in the development of this document.

1.3 Background

1.3.1 PFAS and its use

PFAS are a group of synthetic (i.e. 'man-made') compounds which include Perfluorooctane sulfonate (PFOS), Perfluorohexane sulfonate (PFHxS), and perfluorooctanoic acid (PFOA). PFAS have been widely used around the world since the 1950s to make products that resist heat, stains, grease and water. These include hydraulic fluid, stain resistant applications for furniture and carpets, packaged food containers, waterproof clothing, personal care products and cleaning products.

Due to its effectiveness in extinguishing liquid fuel fires, PFAS was also an ingredient in legacy aqueous film forming foam (AFFF) used extensively worldwide by both civilian and military authorities from about the 1970s. Older formulations of AFFF contained a number of PFAS now known to be persistent in the environment and in humans.

Most people living in developed nations will have some level of PFAS in their body due to their widespread use. In June 2019, the Environmental Health Standing Committee (enHealth)[2], published guidance statements advising that although the scientific evidence in humans is limited, reviews and scientific research to date have provided fairly consistent reports of an association with several health effects. The health effects reported in these associations are generally small and within normal ranges for the whole population. There is also limited to no evidence of human disease or other clinically significant harm resulting from PFAS exposure at this time.[3] However, since these chemicals remain in humans and the environment for many years, enHealth recommends exposure to PFAS be minimised wherever possible.

PFAS contamination on and in the vicinity of the Defence estate has arisen primarily because of the historic use of AFFF for training purposes or incident control.

1.3.2 The nature of PFAS

PFAS has many qualities that combine to present particular challenges in locating, containing and remediating PFAS contamination:

- Water is the prime method of PFAS contamination transferring from a source to a receptor - a person, animal, plant, eco-system, property or a waterbody
- PFAS is highly soluble and mobile and can rapidly leach through soils or disperse in waterways, travelling long distances. This may sometimes reduce the level of contamination of the original source material
- PFAS can permeate some solid surfaces. This includes concrete and other building materials, particularly used in storage tanks, fire training grounds and other large surface areas
- PFAS is very chemically and biologically stable and has a low vapour pressure, so it is resistant to breakdown and evaporation. However, some longer chain PFAS do break down in the environment, and are precursors to forming PFOS, PFHxS or PFOA
- Some PFAS (including PFOS and PFOA) are environmentally persistent and bioaccumulate. This means that some plants may be susceptible to PFAS, up take PFAS via soil and water. It then bio-accumulates and becomes a part of the food chain. The same process applies to some terrestrial and aquatic species.

1.4 Policy context

The policy context for the PMAP consists of national guidance in the form of the PFAS National Environmental Management Plan (NEMP, 2020), Defence estate and environmental strategies, and Defence PFAS-specific strategies and guidance.

[2] EnHealth is a subcommittee of the Australian Health Protection Principal Committee, and is responsible for providing agreed environmental health policy advice. Its membership includes representatives from the Health portfolios of Australian and New Zealand governments.

[3] http://www.health.gov.au/internet/main/publishing.nsf/content/health-pubhlth-publicat-environ.htm

1.4.1 PFAS National Environmental Management Plan

The NEMP aims to provide governments with a consistent, practical, risk-based framework for the environmental regulation of PFAS-contaminated materials and sites. The NEMP has been developed collaboratively by the Heads of EPAs Australia and New Zealand (HEPA) and the Commonwealth Department of Environment and Energy (DoEE)[4] and has been endorsed by the Commonwealth Government.

The PFAS Response Management Strategy and the requirements of the PMAP template and guidance conform to the NEMP (2020). The PMAP template and guidance will be adjusted to conform to relevant changes in the NEMP (2020) as and when changes are made.

1.4.2 Defence estate and environmental management

The Defence Estate Strategy 2016-2036 and the Defence Environmental Strategy 2016-2036 each provide strategic direction for the management of risks associated with PFAS contamination.

Under the Defence Estate Strategy 2016-2036, sustainability is one of five strategic aims for the management of the Defence estate.[5] Under this strategy, the environment and its ongoing sustainable management is viewed as a critical enabler to Defence capability. For legacy contamination, including emerging contaminants such as PFAS, Defence is committed to minimising the impacts of the use of the estate on surrounding communities, proactively investigating and responding to contamination, and working with affected communities and State/Territory authorities.

The Defence Environmental Strategy 2016-2036 provides further strategic focus. Relevant strategic aims are:

Strategic Aim 1:	Defence will deliver a sustainable estate
Strategic Aim 2:	Defence will understand and manage its environmental impacts
Strategic Aim 3:	Defence will minimise future pollution risks and manage existing contamination risks.

1.4.3 PFAS Response Management Strategy

The PFAS Response Management Strategy is a high-level strategy document that sets out the approach and principles to be applied to PFAS response management. Under the Response Management Strategy sit three integrated components:

PFAS Management Area Plan (PMAP) template and guidance	The template on which this PMAP is based, with embedded guidance for the comprehensive PFAS response plan for a Defence Base and its vicinity, based on the outcomes of the Detailed Site Investigations and the risk assessments.

[4] DoEE was dissolved in January 2020 and responsibilities passed onto the Department of Agriculture, Water and Environment (DAWE).

[5] Defence Estate Strategy 2016-2036, Strategic Aim 4: http://www.defence.gov.au/EstateManagement/Governance/EstateStrategy.asp

PFAS Interim Response Management (IRM Guidelines)	Guidance to manage a specific risk rather than the set of risks associated with a property. These risks will generally emerge during the investigation phase. Where it is important that the risk be managed before the conclusion of the Investigation phase or the PMAP is in place, to avoid or mitigate a significant risk to human health or the environment, the IRM guidelines provide a process for developing, assessing and recommending options, scalable from community-level actions through to Public Works Committee (PWC) referral actions.
PFAS Construction and Maintenance Framework	Guidance on the management of PFAS risks when carrying out constructions and maintenance projects on the Defence estate for a site that is, or is likely to be, contaminated by PFAS.

Figure 1 below sets out a strategy and implementation map for Defence PFAS Response Management.

Figure 1: Defence PFAS response management and implementation map

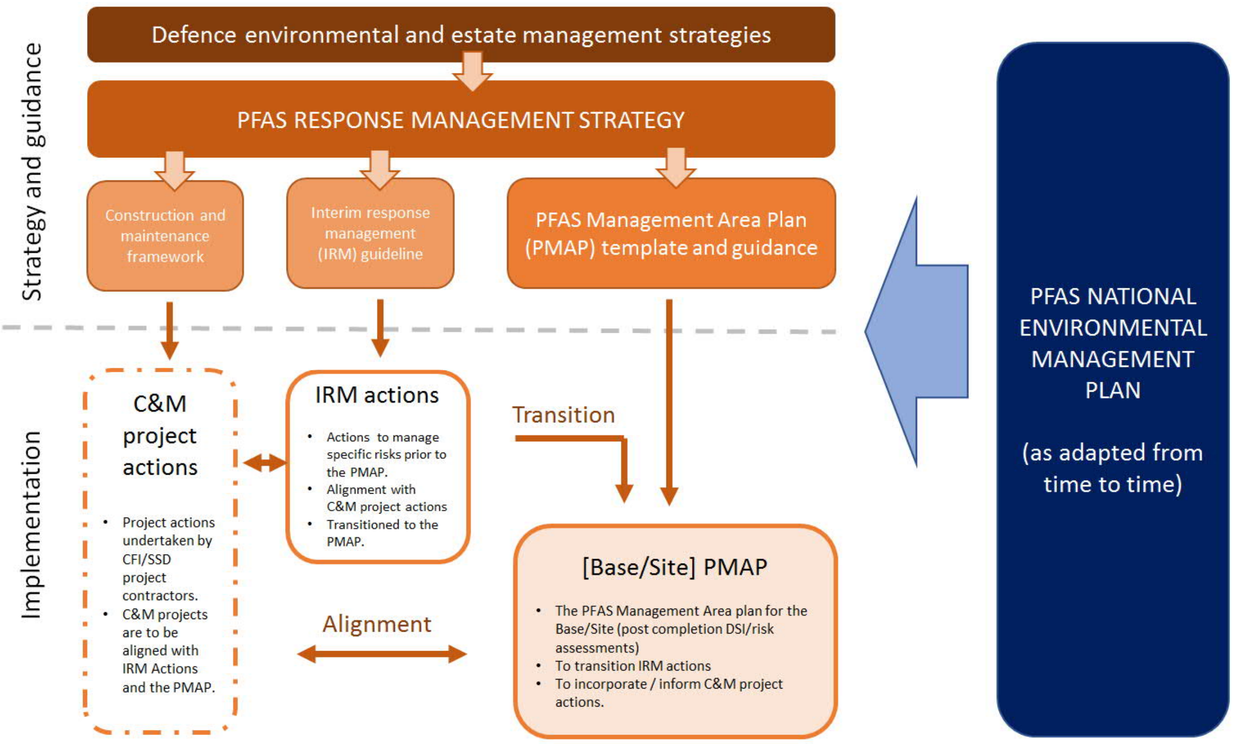


Figure 2 at the end of this section presents the site-management process and the roles of the PMAP and related project documentation.

1.4.4 PFAS Applied Research Strategy

The PFAS Response Management Strategy also guides the PFAS Applied Research Strategy. Its objective is that Defence is sufficiently supported by research and new technologies to efficiently and effectively manage the risks associated with PFAS contamination on or emanating from the Defence estate. This includes supporting demonstration and validating PFAS remediation technologies. The PFAS Technology Demonstration Guideline provides guidance for the processes involved in Defence investment in technology demonstration. The outcomes of program may (as relevant) inform the review of this PMAP.

1.5 Scope

To inform risk identification and weighting for the Management Area this PMAP relies on:

- the Detailed Site Investigation (DSI) report of December 2019 (AECOM, 2019b)
- the DSI Addendum report of 2021 (AECOM, 2021a)
- the Human Health and Ecological Risk Assessment (HHERA) of 2021 (AECOM, 2021b).

The key parameters for the PMAP are set out below.

<table>
<tr><td>Management Area</td><td>On-Site Management Area (Figure F2 – Appendix F): includes on-property areas where the PFAS sources were identified as follows:

Lone Pine Barracks (Cantonment):

Former Fire Station and surrounding area
Defence National Storage and Distribution Centre (DNSDC) Compound
Alternate Landing Ground (ALG)
Helicopter Landing Ground (HLG)

Singleton Training Area (STA)

Dochra Airfield.

Off-Base Management Area: includes properties to the north, north west and north east of the Base. The Off-Base Management Area is intended to show where ongoing monitoring will be implemented on an ongoing basis. It is not intended to show the full extent of PFAS contamination.

Further explanation of the establishment of the Management Area is provided in Section 2.1.

It is noted that PFAS has been detected at some areas both within and outside of the management area (Landfill Areas, Former Landfill and Flame Thrower Range, Former Asset Point and Fuel Compound, Filled Ground Near the Asset Compound and the Honey Pot Compound), however based on the current evidence, these locations do not warrant management (refer to Section 2.1).</td></tr>
<tr><td>Issue/risk identification</td><td>Sourced from the Human Health and Ecological Risk Assessment (HHERA [AECOM, 2021b]), identified as ‘elevated’ risk or equivalent.

<u>Human Health</u>

People who live within the Study / Investigation Area (as defined in the HHERA [AECOM, 2021b]), and who eat a large proportion of their diet sourced from:

Ingestion of home-grown red meat from sheep or cattle that have consumed water containing detectable PFAS, or have grazed in areas irrigated or flooded with water containing detectable PFAS
Ingestion of home-grown milk from cows that have consumed water containing detectable PFAS, or have grazed in areas irrigated or flooded with water containing detectable PFAS
</td></tr>
</table>

	• **Cumulative ingestion of home-grown red meat, of home-grown milk** from cows from sheep or cattle and **of eggs** from home-grown backyard poultry that have consumed water containing detectable PFAS, or have grazed / roamed in areas irrigated or flooded with water containing detectable PFAS. ***Drinking groundwater*** may present a future risk to off-Base users of groundwater (it is not known to currently occur), should the land use change and groundwater extraction occur near the SMA. It is stressed that groundwater is not currently known to be used for drinking water supply within the Study / Investigation Area (as defined in the HHERA [AECOM, 2021b]). As drinking of groundwater is not currently known to occur it has not been assessed in this PMAP, however, should the land and/or groundwater use change in the future this risk may need to be addressed. **Ecological Risk** The ecological risk assessment (ERA) concluded that based on the available data presented and the uncertainties identified, the outcomes of the ERA indicate that there is low to minimal potential for direct or indirect risks to ecological receptors from exposure to PFAS in the ER Investigation Area. Thus, no site management measures are considered necessary to abate PFAS exposure to ecological receptors within the Study / Investigation Area. The identified risks are expanded on in Table 4 in **Section 4.2**.
Issue/risk range	The PMAP addresses the range of elevated risks identified in the HHERA (AECOM, 2021b) but excludes occupational PFAS exposure risks within the Management Area. These are appropriately managed by the relevant contractor in accordance with applicable work, health and safety legislation.
Remediation technology status	The response options in this PMAP consider only proven technologies at the appropriate scale, unless otherwise identified.
Review and Revision	Defence will review and update (where necessary) the PMAP at intervals of 12 months to ensure that the document is current, and its recommendations remain valid. This review will also include ongoing technology performance assessment and review.

1.6 Key response factors

When developing and recommending appropriate response actions, the key response factors considered (in accordance with the Defence PFAS Response Management Strategy and the NEMP) include:

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

Source / Pathway / Receptor: categories of risk management for contamination

A risk occurs when a source of contamination (such as soil contaminated with PFAS) is linked to a sensitive receptor (such as a person) via an exposure pathway (such as stormwater flow to a local water supply).

Response to a risk may involve one or more of the following three principal components:

a) *source management* by removal, destruction, treatment, disposal and/or other methods.

b) *pathway management* by capping, containing, stabilisation, diversion, and/or other methods where the source remains in place but pathways are managed.

c) *receptor management* by relocation, institutional controls, behaviour management, point-of-use treatment and/or other methods focussed on the receptor.

Defence prioritises source management as preferable to pathway management and pathway management as preferable to receptor management but these components may be progressed concurrently in accordance with Defence's priorities as set out in Section 1.1.

1.7 Implementation process

Defence will undertake project management of the overall PMAP, including monitoring of implementation and progressive annual evaluation of the implementation.

This will inform any changes to, and re-alignment of, the PMAP.

Any works or other actions under the PMAP will be subject to Defence approval and procurement processes, including where relevant, the processes of the Parliamentary Standing Committee on Public Works Committee (PWC) processes.

Implementation timeframes will be subject to the factors set out in Section 7.2.

If required, Remedial Action Plans (RAPs) may be developed to better define individual planned remediation actions. The RAPs will describe the purpose and objectives of the remediation, evaluate and determine the remediation options, and set out performance measures. The RAPs will also define the source / pathway that will be addressed. Further information about RAPs is included in Section 5.1.3.

1.7.1 Approvals

a) Higher value public works

Larger public works (exceeding $15 million in expenditure) require a referral to the PWC. Under very limited circumstances, exemptions from the PWC process are available:[6]

- urgency
- for defence purposes where that scrutiny could be contrary to the public interest
- for projects of a repetitive nature.

Medium works (exceeding $2 million but less than $15 million in expenditure) require a notification to the PWC. PWC assessment of a notification may result in:

- approval to proceed
- approval to proceed, subject to specific conditions or requirements
- Committee deliberation postponed, pending further information
- Committee resolution to seek a referral.

For higher value public works, a timeframe of up to 12-24 months may apply before commencement of the development phase of the project to approval to commence the delivery phase. The processes may include all necessary Government and Parliamentary approvals, including PWC. This may require interim measures to be implemented to manage the risks until the response action has received approval to commence.

b) Site Selection Board

Where relevant, the Defence Site Selection Board is required to determine the location of response actions and any supporting infrastructure (for example, containment areas or water treatment plants).

The question as to whether a regional or full review is required will be determined in accordance with Defence Estate Quality Management System (DEQMS) guidance[7].

1.7.2 Procurement phase

Once the PMAP is approved by Defence (and subject to the approvals in Section 1.7.1), Defence will undertake procurement actions (in order of priority) for relevant specific response actions in accordance with the Commonwealth Procurement Rules and standard Defence procurement processes. These specific response actions will be implemented and evaluated in accordance with the terms (including timeframes) of the relevant procurement agreement.

1.7.3 Implementation timelines

The outcomes of the procurement processes will inform the detailed project implementation timelines.

The PMAP is divided into two implementation periods:

1. The **primary implementation period** applies to actions that can generally be addressed in the short to medium term (up to three years, refer Section 7.2). The implementation of the

[6] *Public Works Committee Act 1969*, sections 18(8) and 18(8A)
[7] http://www.defence.gov.au/EstateManagement/lifecycle/SiteSelection/Task4.asp

Ongoing Monitoring Plan will commence in the primary implementation period and extend through to the extended implementation period.

2. The **extended implementation period** commences once the primary implementation period has completed. It applies to response actions required beyond the primary implementation period on an ongoing or long-term basis. These actions include ongoing:

    - monitoring, leachate management, and maintenance of stockpiles
    - monitoring of the Management Area for PFAS
    - ongoing operation of remediation technologies (e.g. a water treatment plant), as required
    - assessment of developments and technologies for application to stockpiled PFAS impacted soils and materials.

Response actions under this PMAP are designated as forming part of:

a) the primary implementation period
b) the extended implementation period
c) both the primary and extended implementation periods (e.g., monitoring of the Management Area for PFAS).

1.7.4 A living document

The science of understanding PFAS impacts and ways of managing PFAS contamination are constantly evolving. There is still a lot that is not established about PFAS behaviour and the impacts of PFAS contamination on human health and the environment. Similarly, remediation technologies of the required scale are at various stages of research and development.

This PMAP has been prepared based on information available at the time of writing and relies on the findings of the DSI (AECOM, 2019b), DSI Addendum (2021a) and Risk Assessments (AECOM, 2021b). Defence recognises that there may still be gaps in information that will be progressively addressed while impacted sites are being managed.

This document will be reviewed annually (or earlier if required). As implementation of the PMAP progresses, detailed plans supplementary to this PMAP will be prepared (as required) to address the individual management actions that have been identified in this PMAP.

1.8 Constraints and assumptions

This document has been developed on the basis of the following assumptions and constraints:

- The state of knowledge presented within the DSI completed in 2019, the DSI Addendum and the HHERA both completed in 2021, including:

    - Historical use of AFFF
    - PFAS results (on- and off-Base)
    - Conceptual site model (CSM)
    - Community surveys.

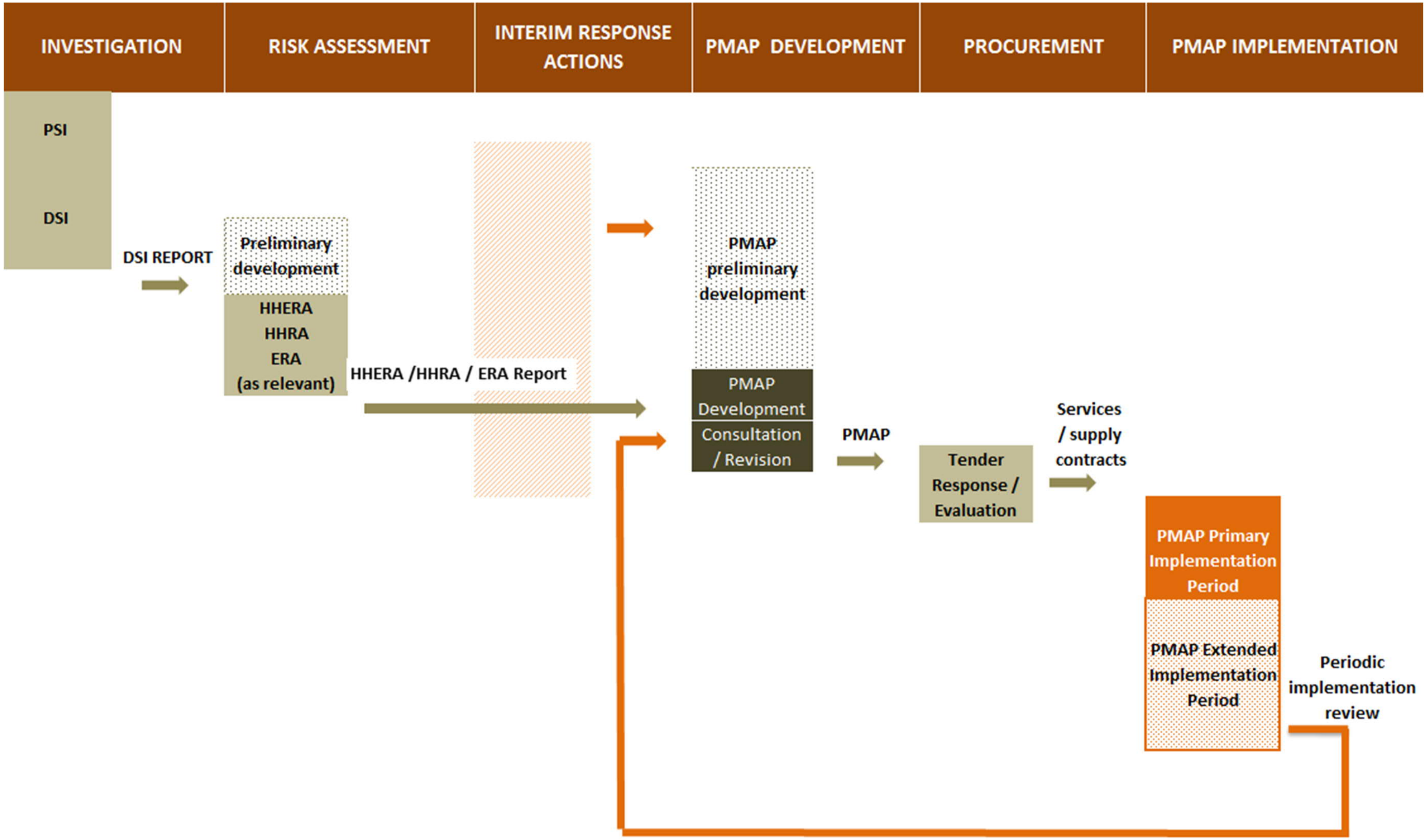
- Proposed management/remediation options based on current proven technology available at the time of writing this document:

    - Management and remedial technologies summarised in the PFAS NEMP (2020)
    - Additional technologies based on successful trials within and outside of Australia (based on publicly available information)

  - Technologies that are not considered economically viable or feasible for use at the Management Area have been excluded (as recommended in PFAS NEMP [2020]).

- Government issued guidelines, advisories and policies
- Base infrastructure development and access constraints at the time of this report
- Access to off-Base private properties will be granted.

Figure 2: Defence PFAS management process map



2 PROFILE OF THE MANAGEMENT AREA

2.1 Management Area description

The Management Area comprises the Singleton Military Area (SMA) and neighbouring properties to the north, north west and north east.

The SMA is comprised of Lone Pine Barracks (the Cantonment) and the Singleton Training Area (STA) and is located approximately 8km south of the township of Singleton. The SMA comprises the barracks houses, the School of Infantry, Joint Logistics Unit East (Hunter Valley), the Australian Army Infantry Museum as well as Estate & Infrastructure Group SMA. Support activities undertaken primarily at the Barracks include vehicle maintenance, storage and distribution of fuels and equipment wash-down. A fire station was operational at the Barracks between 1963 and 1994, and associated activities included historical firefighting training with AFFF and equipment maintenance and testing. AFFF is no longer stored or used at the SMA.

The STA is an approximately 15,000 hectare firing range located between the Cantonment (to the north), Brokenback Range (south), the Hunter Vineyards (east), and the Mount Thorley Mine area (west). The STA is comprised of a number of former and active ranges for weapons firing, vehicle training and explosives testing.

PFAS source areas are described in more detail below and their locations are presented on **Figure F2** in **Appendix F**.

<u>SMA (On-property) source areas</u>

- Former Fire Station Area – The former fire station was operational between 1963 and 1994 and used for the storage of AFFF and firefighting equipment, and for firefighting training and equipment maintenance and testing activities. Firefighting training involved the excavation of shallow pits up to 1 metre below ground surface (m bgs), followed by ignition of solid fuels which were extinguished using AFFF formulations. Firefighting training was also conducted on a concrete pad to the south of the former fire station building, and in shallow pits (unsealed ground) to the west of the building. Excess foam (spent AFFF) was disposed to ground to the south of the building with runoff draining overland to the south-west. Fire trucks were also washed down with AFFF to the west of the building
- Fire truck service pumps were also tested by pumping water from a large diameter well (CNN0018_GW03) located in the hardstand behind the former fire station building. Although it is unknown if the large diameter well is lined, it is likely that a conductor casing would have been installed to keep the unconsolidated material from caving in the well, which is standard practice in large diameter well construction. Hoses used to pump groundwater may have introduced AFFF to the well. It is noted that AFFF was discharged to the ground, not into the well
- Defence National Storage and Distribution Centre (DNSDC) – This has been in operation since 1963 and is used for the storage of fuels, oils and other chemicals, incineration of waste fuels, and maintenance on vehicles and equipment. Maintenance has been periodically conducted on fire trucks at the compound and involved testing and purging of fire hoses and equipment. AFFF was historically discharged from fire trucks and drained to the creek to the east of the compound. Anecdotal information suggests AFFF was periodically discharged to ground surface adjacent to a tree in the central compound as part of non-military activities by personnel
- Alternate Landing Ground (ALG) - The ALG is used sporadically by the Army and Royal Australian Air Force. Units that use the airfield are responsible for providing their own firefighting capabilities and exact quantities and types of AFFF used at the airfield unknown. Anecdotal information suggests AFFF was likely discharged during line testing on fire trucks prior to aircraft

landing, and during potential emergency responses activities. Line testing was conducted adjacent to the windsock to the north of the airstrip

- Dochra Airfield - The airfield is located in the north-east of the STA and is used sporadically by the Army and Royal Australian Air Force. Anecdotal information suggests AFFF was likely discharged during line testing on fire trucks prior to aircraft landing, and during potential emergency responses activities. Most activity was concentrated at the northern and southern aprons and airstrip runoff areas. Mudies Creek and Emigrant Creek flank the Airfield and receive runoff from the area via overland flow (Figure F3 in Appendix F). Downstream of Dochra Airfield, both creeks flow off Base towards the Hunter River
- Helicopter Landing Ground (HLG) - The HLG operated in the open space behind the current Q Store. The helicopter landing area was used for re-fuelling and training until the mid-1990s. Anecdotal information suggests a portable tank containing AFFF was permanently stationed here during operation
- Landfill Areas - A number of former shallow waste burial areas are located across the Cantonment and were used for the disposal of demolition waste materials, refuse from historic base operations and domestic activities. The historical practice of crushing and burning landfill material may also have required the use of AFFF to put out fires. Several landfills are located close to the Fire Station and are considered to have a higher probability of receiving Fire Station-related wastes historically

  The soil results from the Landfill Areas, were below the adopted human health (commercial/industrial and public open space land uses) and ecological criteria (indirect exposure – commercial/industrial land use). These results indicate that PFAS impact in this area is limited in nature and unlikely to be contributing to off-Base impacts. **Therefore, these potential sources are not considered for further assessment or management**
- Former Landfill and Flamethrower Range - Former training range used for flamethrower training exercises. Historical information suggests hydrocarbon propellants were stored at or close to the range. Potential AFFF use is considered low. Fires were extinguished with fire blankets.

  Results from the Detailed Site Investigation (DSI, 2019b) indicate that the detectable concentrations of PFAS are limited in nature and unlikely to be contributing to off-Base migration of PFAS concentrations greater than adopted human health criteria. **Therefore, this source is not considered for further assessment or management**
- Former Asset Compound and Fuel Point - Constructed between 1963 and 1974. Bulk storage of petroleum and diesel in two 15 kL USTs and oils in several 210 L drums prior to demolition in 1990. Fire suppression infrastructure and history of emergency firefighting activities is unknown. At the Fuel Point, bulk quantities of petrol and diesel are stored in five underground storage tanks in the area. Potential historical AFFF use during training or emergency response activities is not known

  Analytical results from the subsurface investigations were below the adopted human health (commercial/industrial and public open space land uses) and ecological criteria (indirect exposure – commercial/industrial land use). While PFAS has been detected at the source area, the results indicate that the detectable concentrations of PFAS are limited in nature and unlikely to be contributing to migration off-Base. **Therefore, this source is not considered for further assessment or management**
- Filled Ground near Former Asset Compound – One groundwater sample collected from Filled Ground near former asset compound had detectable concentrations of PFOS + PFHxS (0.008 µg/L) close to the laboratory limit of reporting (LOR). These results indicate that the detectable concentrations of PFAS are limited in nature and unlikely to be contributing to migration off-Base **Therefore, this source is not considered for further assessment or management.**
- Honey Pot Area - Sewage and surplus liquid wastes disposal area located at the Centre Ridge accommodation compound. Sewage was typically stored in personal containers by SMA personnel during training exercises conducted at the STA. The containers, colloquially called “Honey Pots” were emptied at the area following completion of exercises. The exact location and

typical volumes of liquid disposed of at the area are unknown. Potential AFFF use is considered very low
All soil results were below the adopted human health (commercial/industrial and public open space land uses) and ecological criteria (indirect exposure – commercial/industrial land use). These results indicate that the detectable concentrations of PFAS are limited in nature and unlikely to be contributing to migration off-Base. **Therefore, this source is not considered for further assessment or management**

- Demolition Ranges- Four active and former demolition ranges were investigated at the STA. PFAS were not detected above the LOR in any surface samples collected at the ranges indicating historical AFFF use was limited or potentially not undertaken. The results agree with anecdotal accounts of fire management protocols at demolition ranges provided by SMA personnel. **Therefore, these potential sources have not been considered for further assessment or management.**

Off-property source areas

- Singleton Sewage Treatment Plant (STP) – The Singleton STP receives wastewater from both the SMA and wider Singleton township. Therefore, wastewater from an unknown number of domestic and industrial facilities may contribute PFAS to the sewage inflow (including some potential PFAS sources outlined below). There is potential for the Singleton STP to collect and then redistribute PFAS to the environment, given that the treatment process has not been designed to address PFAS concentrations. While the inflow/outflow from the STP is relatively continuous, the limited temporal data indicate that PFAS concentrations in the influent and effluent vary over time (AECOM, 2021a). As noted above, the treatment process at the Singleton STP is unlikely to remove / treat PFAS and therefore PFAS may be present in effluent and biosolids produced. Council has advised that treated water from the STP is continuously discharged into the Doughboy Hollow Creek water course directly north of the STP at a rate of 2,500-3,000 kilolitres (kL) per day. It is understood from discussions with Council that biosolids generated are disposed to landfill
- Former Council sullage tip (potential source) – a property that borders the SMA, north east of the Cantonment. The volume and nature of waste received by the tip are unquantified. Potential for PFAS-impacted waste (similar to that received by the STP) to have historically been received by the tip
- Whittingham Airstrip (potential source) – a low traffic private airstrip servicing light aircraft. There is potential for storage of AFFF and use during training and/or emergency response activities to have occurred
- Whittingham Fire Station (potential source) - Operational, Council-owned fire station located on Range Road. Potential for storage of AFFF, and use during training exercises, emergency response and maintenance activities to have occurred
- Hunter Valley Mines Rescue Facility - Located Approximately 2 km north-west of the Hunter River. Is an EPA listed PFAS-impacted site PFAS has been previously detected on and off-Base
- Fire and Rescue NSW, Singleton Station (potential source) - Located within Singleton CBD, approximately 500 m south-east of the Hunter River. Likely historic storage of AFFF and discharge to ground during training exercises, emergency response and maintenance activities
- Anecdotal evidence of vehicle incidents on the highway surrounding the Base (potential source) - AFFF containing PFAS may have been used in emergency response situations. AFFF discharged at the scene of vehicle accidents would likely migrate to soil, surface water drainage lines and groundwater and act as an ongoing secondary source
- Coal mine operations (potential source) - Bulga and Mt Thorley mines border the western boundary of the STA. Extensive coal mine operations in the Hunter Valley within the catchment of the Hunter River. Potential for storage and use of AFFF during routine firefighting training and

protection of large mining equipment. Potential migration from the sites via surface water and groundwater has not been evaluated

- NSW Rural Fire Service (potential source) - Potential historic storage of AFFF, and use during training exercises, emergency response and maintenance
- Extracted groundwater and or surface water (potential source) - Extraction of groundwater and diversion of surface water from creeks and other waterbodies by residential, recreational and commercial users. From the Water Use Survey (AECOM, 2021b), groundwater and surface water are known to be used for a variety of purposes
- Off-Base sources have the potential to contribute PFAS-impacted water to local surface water drainage lines, and shallow groundwater that may be abstracted by other users for irrigation, domestic or potable use.

2.2 Management Area setting

2.2.1 Climate

The climate at the SMA is characterised as temperate, with cool winters and warm summers. Winter months (May – October) are typically drier than summer months (November – April). Rainfall has been monitored on-site at Bureau of Meteorology (BOM) station 61430 since 2017. Historical records of average annual rainfall have been recorded at the BOM station Broke (station number 61100), which is located approximately 7 km away from the SMA.

Rainfall monitored on-site at BOM station 61430 between January 2018 and June 2020 is presented in the HHERA (AECOM, 2021b). This indicates that rainfall prior to the PSI sampling period in October 2018 was below average. The comprehensive surface sampling round conducted in April 2019 as part of the DSI (AECOM, 2019b) was in response to the moderate rainfall received in March 2019. A moderate amount of rainfall was also received between January and April 2020, allowing formerly dry ephemeral waterbodies to flow again and to be sampled as part of HHRA and ERA fieldwork (as required).

2.2.2 Topography

The SMA is located approximately 40 kilometres east of the Great Dividing Range and is dominated by moderate to gently sloping hills, with the foothills of the Brokenback Ranges rising steeply at the southern extent of the STA.

The topographic zone assigned to the majority of the off-Base Investigation Area is the Central Lowlands, which are located along the Hunter River and typified by undulating to rolling hills on weak sedimentary rocks.

2.2.3 Surface Water

The Management Area for this PMAP spans the catchment areas of several creek lines that ultimately drain north and eastwards to the Hunter River located approximately 2 km from the Site’s northern boundary. The key on-Site drainage lines investigated as part of the DSI (AECOM, 2019b) include:

- Mudies Creek and Emigrant Creek, which are located along the western and eastern boundaries of the Dochra airfield at the STA
- Peach Tree Creek, Monkey Place Creek, Loder Creek, Nine Mile Creek, Rothbury Creek and Jump-up Creek, which emanate from the STA but are not located within the areas assessed by the HHERA (AECOM, 2021b). These watercourses were assessed in the Preliminary Site Investigation (PSI) (AECOM, 2019a) and, based on non-detection of PFAS and lack of identified source areas, were not considered further during the DSI or HHERA

- Doughboy Hollow Creek, which traverses both the Cantonment and the STA, and then runs in a northerly then easterly direction off-Base along the western and northern SMA boundaries respectively.

Doughboy Hollow Creek and a number of its tributaries traverse the Cantonment and are connected to engineered drainage channels. The DSI (AECOM, 2019b) divided the SMA catchment into three sub-catchments (as presented on **Figure F4** in **Appendix F**) as follows:

- Sub-catchment A (refer to Figure F4): Northern portion of the Cantonment. The primary drainage line is an un-named tributary of Doughboy Hollow Creek which flows in a northerly direction and discharges off-Base at the northern Cantonment boundary. In addition to runoff via defined the unnamed tributary of Dough Boy Hollow Creek, surface water runoff from the Cantonment during heavy rainfall events may occur via overland flow. Notably, runoff generated at the DNSDC (located within sub-catchment A) appears to drain north towards the northern boundary of the site via overland flow before crossing beneath the railway line and entering a dam within Council-owned land
- Sub-catchment B (refer to Figure F4): Central portion of the Cantonment. The primary drainage line is an un-named tributary of Doughboy Hollow Creek which flows in a north-westerly direction and discharges off-Base at the western Cantonment boundary down-gradient of the HLG
- Sub-catchment C (refer to Figure F4): Southern portion of the Cantonment. The primary drainage line is the main watercourse of Doughboy Hollow Creek which flows in a north westerly direction and discharges off-Base at the western Cantonment boundary in the vicinity of the landfill and former flame thrower range.

As previously stated, Doughboy Hollow Creek flows from across the western boundary of the Cantonment (sub-catchment C), then flowing in a north / north-westerly direction (within the Investigation Area), then turning north east towards Army Camp Road north of the Cantonment.

Whilst a shallow drain continues east towards a culvert under Army Camp Road, AECOM observed during the DSI (AECOM, 2019b) that surface water was not present at this location and it is was inferred that the creek on most occasions soaks through the alluvial soils, providing recharge to groundwater.

The Doughboy Hollow floodplain, including lower portions within the Whittingham area, and part of the wider Hunter River alluvial floodplain, is understood to be prone to waterlogging and flooding during heavy rainfall events. Review of aerial imagery of surface water flow paths following a flood event in January 2016, indicated that following periods of heavy rainfall, Doughboy Hollow Creek can flood large portions of the off-Base Investigation Area, forming continuous flow paths between Doughboy Hollow Creek at the Cantonment and the wetland east of the STP.

The wetland east of the STP is understood to have hydraulic connectivity with groundwater present within the Hunter River alluvial floodplain at Whittingham. Therefore, surface water that migrates from Doughboy Hollow Creek to the wetland area east of the STP may provide recharge of groundwater present in the Hunter River alluvial floodplain.

It is noted the DSI (AECOM, 2019b) was completed during a period of drought and hydrological observations were limited due to the absence of surface water within the Investigation Area. Additional inspections completed during the HHERA (AECOM, 2021b) and the supplementary sampling program (AECOM, 2021a) were undertaken during relatively wetter climatic conditions and observations confirmed:

- Doughboy Hollow Creek does not continue downstream of the culvert at Army Camp Road and appears to soak away to alluvial soils.
- The dam on the eastern side of Army Camp Road (downstream of the culvert) primarily receives inputs from the unnamed tributary of Doughboy Hollow Creek that drains sub-catchment A. The tributary leaves the Cantonment at the northern boundary and flows through location HHRA36 (refer to AECOM, 2021a) before reaching the dam.

Mudies Creek and Emigrant Creek flow off-Base from the northern boundary of the STA and meet to the east of the Cantonment, with Mudies Creek continuing north-east towards the Hunter River.

Other than Doughboy Hollow Creek, Emigrant Creek and Mudies Creek, off-Base waterbodies within the Management Area include a number of private dams and smaller drainage lines located on residential properties. In addition, an area of Council land east of the STP was observed to be largely inundated during the DSI (AECOM, 2019b), with the water considered to be at least partly sourced from discharges from the STP. This area was subject to a survey by an aquatic ecologist from Austral as part of the ERA (AECOM, 2021b) sampling program. The ecologist described this area as a wetland[8] situated in an agricultural landscape that is regularly grazed by cattle (refer to AECOM, 2021b). Council has advised that treated water from the STP is continuously discharged into the Doughboy Hollow Creek water course directly north of the STP.

Aerial imagery of surface water flow paths following a flood event (refer to AECOM, 2021b) illustrates that following periods of heavy rainfall, Doughboy Hollow Creek floods large portions of the off-Base Management Area, forming continuous flow paths between Doughboy Hollow Creek at the Cantonment and the wetland east of the STP. Downstream of the wetland area, water flow continues via Doughboy Hollow Creek, flowing in a south-easterly direction and meeting Mudies Creek outside the Management Area. These surface water flow paths are presented on **Figure F4** in **Appendix F**. Given its ephemeral nature, during periods of low rainfall, Doughboy Hollow Creek is unlikely to extend to the northern portions of the Management Area or be continuous with Mudies Creek.

During previous investigations all the major surface water bodies were observed to be ephemeral across the SMA and off-Base Management Area over the course of the AECOM field program from 2018 to 2020. These surface water bodies flow in response to rainfall with no baseflow component connected to regional groundwater, with the exception of the continuous flow paths between the wetland east of the STP and Doughboy Hollow Creek, which are recharged by the continuous discharge from the STP. Sampling activities undertaken as part of the PSI (AECOM, 2019a) were completed during a period of drought so surface waters generally comprised stagnant, disconnected pools of water which hindered the collection of surface water at many locations. More rainfall was recorded during the DSI; however, the observations were generally consistent with the PSI, with sample locations having little to no surface water flow. Significant rainfall was encountered prior to HHRA and ERA sampling, allowing surface water flows to be observed.

There is a potential for surface water to recharge groundwater in the Management Area. A review of major ion composition completed for 55 groundwater and five surface water samples as part of the DSI (AECOM, 2019b) found that surface water is reasonably distinct from groundwater, with surface water samples reporting a much lower dissolved ion content, much lower electrical conductivity (EC) and lower cation concentrations. Therefore, available data indicate that surface water and groundwater interaction is likely to be limited, with surface water appearing to be relatively fresh and fed directly by rainfall. All the samples (except one groundwater sample) reviewed in the DSI (AECOM, 2019b) as part of this exercise were collected from the site, and therefore these conclusions apply to the site only (not off-Base areas).

Key surface water drainage features are shown on **Figure F4** in **Appendix F** and surface water flows from Source Areas are discussed in **Table 3**.

[8] Department of Agriculture, Water and the Environment classifies a "wetland" as an area of land where water covers the soil all year or just at certain times of the year. These areas include, but are not limited to, swamps, marshes, lakes, mangroves and bogs (DoAWE, 2020).

2.2.4 Flora and Fauna

The EPBC Protected Matters Search Tool (PMST) (DoEE, 2020) search within 5 km of the Management Area identified 41 listed threatened species, notably the following species or species habitat which are known to occur:

- Birds: the regent honeyeater[9] and swift parrot[10] are critically endangered.
- Mammals: the spot-tailed quoll[11] is endangered
- Plants: Euphrasia arguta (annual herb) and Prasophyllum sp. Wybong (terrestrial orchid) are critically endangered
- Reptiles: the broad-headed snake is vulnerable.

This is in addition to a range of species identified to potentially occur in the area.

The following fauna have been observed by AECOM field staff within the Investigation Area[12] (as defined in the HHERA):

- Numerous birds, including small eagles, falcons, black cockatoos and tawny frogmouth owls. A wedge-tailed eagle was observed at the Dochra Airfield, with three breeding pairs previously identified on the STA by site staff
- Kangaroos across the Investigation Area
- Wild horses across the STA
- Wild dogs, wild boars and foxes at various locations across the STA (considered to be pests with low ecological value)
- Tadpoles and frogs at numerous locations across the Investigation Area
- Goannas, including a lace monitor (approximately 1.5 m in length) at the Cantonment
- Frilled-neck lizard at the Cantonment
- Red-bellied black snake centrally within the STA
- Possum within the Dochra Airfield
- Small tortoise on the boundary between the Cantonment and the STA
- Turtle within an off-Base drainage line east of the Cantonment
- Crab legs at Mudies Creek within the Dochra Airfield.

An ecological survey of terrestrial habitats completed as part of the HHERA, identified one threatened species: the River Red Gum, whose Hunter population is listed as endangered under the BC Act, was observed at the ERA-2 survey area at the Cantonment. No threatened fauna species were observed, and a habitat assessment performed by NGH noted that threatened amphibian species are considered unlikely to occur within the surveyed areas (AECOM, 2021b). Fauna opportunistically observed during the terrestrial survey include the following:

- Noisy miner
- Australian raven
- Brush-tailed possum
- Eastern grey kangaroo
- Australian wood duck

[9] The regent honeyeater primarily feeds on nectar and other plant sugars. It can also feed on insects and spikers as well as native and cultivated fruits.

[10] The swift parrot mainly feeds in the canopy of flowering eucalyptus, eating mainly nectar as well as phyllids, lerps, seeds and flowers

[11] The spotted quoll's diet comprises small mammals (such as gliders and possums), reptiles, invertebrates, birds and eggs,

[12] During the PSI (AECOM, 2019a), DSI (AECOM, 2019b), field visit by ecological risk assessment team (AECOM, 2019c) and fieldworks undertaken as part of this HHERA.

- Yellow-tailed black cockatoo.

The ecological survey of aquatic habitats identified a range of aquatic invertebrates at surveyed locations, including lower trophic level species (e.g. gastropods) and higher trophic level species (e.g. yabbies). The aquatic survey additionally identified a range of finfish, including lower trophic level species (e.g. gambusia) and higher trophic level species (e.g. eel). A range of emergent and submergent macrophytes (aquatic plants) were also identified at each sampling location. A spotted marsh frog was identified in the wetland east of the Singleton STP.

2.2.5 Regional Geology

The SMA is located within the northern part of the Sydney Basin which is characterised by Permian and Triassic aged sediments. The sediments are predominately fresh water with some marine, terrestrial and coal deposits. The predominant lithology at the SMA is Narrabeen Group which is composed of sandstone with some conglomerate, claystone and shale. Other rocks present are quartzose sandstone of the Hawkesbury Sandstone, siltstone and tuff. Coal measures are also extensive consisting of black coal interbedded with sandstone, shale mudstone, conglomerate with minor chert and tuff.

The Management Area is covered by a diverse range of soil types, as identified from the Soil Landscapes of Singleton 1:250,000 sheet, (Kovac, M. and Lawrie J. 1991). The soils within low-lying parts of the SMA and the off-Base Management Area consist principally of alluvial soils, yellow and red podzolic soils. In the more elevated areas to the south the soil profiles are thinner and are classified as shallow soils. Quaternary alluvial deposits of gravel, sand and silt and clay are most pronounced along the floodplain of the Hunter River (for which Doughboy Hollow floodplain is a part).

2.2.6 Hydrogeology

The hydrogeology of the Management Area can be divided into four notable subunits:

Perched Groundwater unit

Unconfined discontinuous perched groundwater within the sediments flanking creeks. Groundwater is present within discontinuous alluvium/colluvium flanking major water courses across the Management Area. The groundwater is perched and recharged by rainfall in the catchment, though storage is extremely limited due to the shallow and narrow nature of the alluvial/colluvial material. The zone of saturation would periodically dry out following extended periods of low rainfall and is susceptible to contamination due to its unconfined nature and transmissive properties.

Alluvial Groundwater

Groundwater is present in the low-lying part of the Management Area to the north-west, north and north-east of the SMA within the alluvial sediments of the Hunter River floodplain. Groundwater is predominantly recharged from surface water and from the Hunter River and its tributaries, and locally enhanced by rainfall runoff and infiltration.

High yields of good quality water can be pumped from the aquifer making it a resource for beneficial uses including irrigation, agriculture and farming.

Shallow Groundwater unit

Shallow perched groundwater within weathered zone of the Permian bedrock. Groundwater is ephemeral with its presence being reliant on rainfall. The groundwater becomes perched above zones of low hydraulic conductivity such clay or shale lenses within the clayey lithology. The presence of groundwater is dependent upon structures within the geological sequence where water can become perched groundwater levels are highly variable. Additionally, local variations in relief (i.e. dip direction of the bedding) at the soil / bedrock interface may add further complexity to groundwater mobility and flow direction. Groundwater quality within this unit is generally poor due to the leaching of salts from the Permian bedrock. Perched groundwater sitting in the unconsolidated material above the shale bedrock, is discontinuous in nature, but generally flows in a north/north-easterly direction towards the Hunter River.

Deep Groundwater unit

The dominant bedrock aquifer across the SMA; forms the regional aquifer. Groundwater flow through the aquifer is highly variable depending primarily on rock porosity and interconnection of void space between grains of the rock, and secondarily on structural features such as joints, fractures, bedding layers and shear zones. Groundwater flow through the aquifer is highly variable depending on the lithological conditions and the degree of fracturing.

The coal layers contain a large volume of groundwater. Groundwater quality within this unit is generally poor, with salts leaching from the sedimentary rocks.

The regional groundwater in the shale bedrock at the Cantonment was shown to flow in a north/north-easterly direction towards the Hunter River (AECOM, 2021a). Shallow groundwater sitting in the unconsolidated material above the shale bedrock, is discontinuous in nature, but generally flows in a north/north-easterly direction towards the Hunter River.

At the STA, around Dochra Airfield, the regional groundwater in the shale bedrock flows in a northerly direction towards the Hunter River.

2.2.7 Current and Projected Land Uses Surrounding the Management Area

Current Land Uses

The uses of land surrounding the SMA are summarised in **Table 1**. It is anticipated that the land uses surrounding SMA will remain reasonably similar for the foreseeable future. However, any new information pertaining to changes in land use could trigger a review and/or update of the HHERA (AECOM, 2021b). Additionally, it is noted that there is the potential that off-property activities and/or businesses may have used or generated wastes containing PFAS for various purposes.

Table 1: Land Uses surrounding the Singleton Military Area

Direction	Description
North	The Cantonment is bounded by grazing land within Doughboy Hollow and the floodplain areas of Whittingham and Glenridding. An STP owned by Singleton Council (the Singleton STP) is located within Doughboy Hollow. Further to the north lies the township of Singleton and the Hunter River. The Whittingham Fire Station and Whittingham Airstrip are located 1 km and 1.3 km north east of the Cantonment, respectively.
South	The STA is bounded to the south by the rugged terrain of the Pokolbin State Forest and the Brokenback range. Further to the south east are the Hunter Valley vineyards of Pokolbin.
East	Rural and semirural land holdings including pastureland and sparsely wooded open land. The Hunter River lies to the north east. Irrigated cropland dominates within the floodplains of the Hunter River.
West	The western boundary of the Cantonment is bounded by grazing land within the Doughboy Hollow, and irrigated cropland within the floodplains of the Hunter

	River. Further west are the Hunter River, Mount Thorley/Warkworth and Bulga Open Cut coal mines and associated buffer areas.

2.3 Management Area complexity scale

The scale of the complexity of the Management Area is rated as **Medium** in accordance with the table below.

	Characteristics	Consequences
Very Large	• High number of identified risks • Multiple areas of contamination, both on-Base and off-Base • hydrogeological profile facilitates rapid migration of contamination • large impacted community	– PMAP complex – Development / implementation timeframe: highly extended
Large	• Medium number of identified risks • Multiple areas of contamination, both on-Base and off-Base • Medium-sized impacted community	– PMAP moderately complex – Development / implementation timeframe: extended
Medium	• Small-medium number of identified risks • Localised areas of contamination both on-Base and off-Base	– PMAP simplified – Development / implementation timeframe: medium
Small	• Small number of identified risks • Contamination currently confined to isolated locations on-Base • Potential risk of contamination to a small number of sensitive receptors	– Basic PMAP – Development / implementation timeframe: medium

2.4 Extent of contamination

The Conceptual Site Model (CSM) in Section 4 identifies the source areas (primary and secondary), migration pathways and receptors.

The nature, extent, fate and transport of the contamination within the Management Area are based on the DSI (AECOM, 2019b) and DSI Addendum (AECOM, 2021b) as described below.

2.4.1 PFAS Source Areas

__On-base PFAS Source Areas__

Five PFAS source areas were identified in the DSI (AECOM, 2019b). These areas were:

- Former Cantonment Fire Station and fire training pits (PFAS in soil, groundwater and concrete).
- DNSDC (PFAS in soil, groundwater, surface water and sediment)
- ALG (PFAS in soil, surface water and sediment)
- Dochra Airfield (PFAS in soil, groundwater, surface water and sediment)
- HLG (PFAS in soil, groundwater, surface water and sediment).

The discharge of AFFF (3M Lightwater) to land is suspected to have occurred at these areas during historical routine operations (including handling and storage) and firefighting training exercises.

Reported concentrations of PFAS were generally below relevant direct contact health and ecological guidance values for potentially active exposure pathways (ways that people or the environment could be exposed to PFAS). Exceptions were at the area surrounding the Former Cantonment Fire Station where several exceedances of health-based guidance values (for residential and public open space land uses) and at several source areas for ecological guidance values. It is also noted that no soil samples have been collected in the vicinity of the existing monitoring well (CNN0018_GW03) located at the Former Cantonment Fire Station, which has the highest PFAS concentrations in groundwater across the SMA. This monitoring well is located close to the former large diameter well used for pump testing. Although there is a potential for soil concentrations in this area of the former fire station to be higher than the current soil data set, they are expected to be limited in extent based on the density of sampling that has occurred.

Further details of the PFAS source areas are provided in **Section 4.1** below.

<u>Off-base PFAS Source Areas</u>

Several off-Base potential PFAS source areas were identified, in the DSI (AECOM, 2019b) including: the Singleton STP (included in this PMAP Management Area and OMP); the Former Council sullage tip; the Whittingham Airstrip; and the Whittingham Fire Station. Additionally, detectable concentrations of PFAS were reported in shallow soil samples located on private properties to the south of Range Road, in the vicinity of ephemeral drainage lines that drain onto the Base via sub-catchments B and C during the HHERA (AECOM, 2021b).

These off-base source areas are potentially contributing to PFAS contamination within the Management Area (refer to **Section 2.1** for full list and descriptions, note that some sources are outside the Management Area). With the exception of the STP, which receives sewage contributions from the Base, off-site source areas are not considered further in the proposed PMAP or OMP activities. PFAS concentrations in shallow and deep groundwater are limited down gradient of the Cantonment boundary marginally extending into the Doughboy Hollow Creek floodplain (AECOM, 2021a) (refer to Figure F5a of the OMP, in Attachment 1). Therefore, there is not a continuous PFAS groundwater plume from on-Base sources through to the off-Base Management Area. The off-Base groundwater plume identified in the northern and north western portions of the Management Area is considered unrelated to groundwater impacts identified at the Cantonment (AECOM, 2021a).

A number of catchments south of Range Road, drain onto Base, sampling conducted on private properties in this area as part of the HHERA (AECOM, 2021b) indicated soil impacts, implying there may be an unidentified off-Base source of PFAS in this area. Surface water sampling conducted between the Base and these properties did not report concentrations of PFAS, indicating that impacts are not currently migrating onto the SMA.

2.4.2 Transport Pathways

Sampling of surface water and sediment in the creeks that drain the SMA identified that PFAS is migrating from on-base source areas via surface water. These off-Base surface water discharges occur via:

- Mudies Creek, Emigrant Creek discharging from the STA and ultimately towards the Hunter River
- Doughboy Hollow Creek, flows from the Cantonment (sub-catchment C) and off-Base to the west of the Cantonment in a north-westerly direction (outside of the Management Area), turning north east towards Army Camp Road north of the Cantonment (entering back into the Management Area).
  Down gradient of the STP it is likely that Doughboy Hollow Creek soaks through the alluvial soils, providing recharge to groundwater (refer to Section 2.2.3). This groundwater may then be used for irrigation (north, north east and east of the wetland, and particularly east of New England Highway), redistributing PFAS impacts across a broader area, which will ultimately migrate back to groundwater
- The sewer which connects the SMA to the Singleton STP
- Overland flow to the east of Sub-Catchment A down gradient of the DNSDC

- Drainage line down gradient of the Alternate Landing Ground (within Sub-Catchment A) which discharges off-Base under Range Road.

Residual PFAS within the soil and sediment profiles can leach to surface water and groundwater, and there is evidence that surface water also infiltrates vertically to groundwater. Following heavy rainfall, surface water is noted to accumulate in the Doughboy Hollow floodplain, located down-gradient and to the north-west of the Cantonment. Surface water flows that accumulate here may allow contaminants to seep into the shallow groundwater present within the alluvial soils of the Hunter River floodplain (refer to Doughboy Hollow Creek discussion above).

Groundwater flow direction (within the deeper aquifer) from the SMA is to the north and north-east towards the Hunter River (AECOM, 2021a).

The spatial distribution of PFAS detections in groundwater is limited and, in some cases isolated, and it is considered unlikely that groundwater migration is a significant transport mechanism off-Base. Based upon the body of evidence, the current and principal PFAS migration pathway appears to be via surface water, including areas of overland flow. Catchment drainage regimes at the SMA are characterised by rapid overland flow and little ponding in the upper catchments, and more defined flows with greater potential for ponding in the lower catchments.

2.5 Groundwater use

There are currently no restrictions on the beneficial use of extracted groundwater within the Management Area, although there are licensing/approval requirements.

A search of registered bores identified 117 bores within 2 km of SMA listed as being used for household water supply, irrigation or livestock watering. Water use surveys conducted during the DSI (2019b) and HHERA (2021b) found that of the 45 respondents who live within the Investigation Area, seven used bore water at their properties at the time of responding to the survey. The registered groundwater bores are predominantly located to the south-west, north-west, north and north-east of the SMA.

The main observations from the water use surveys included:

- the primary source of water in the off-Base Investigation Area is from mains water supply or rainwater tank connection
- residential properties are susceptible to flooding during periods of high rainfall
- groundwater is abstracted and used at properties for non-potable domestic supply
- nine respondents indicated that they use the dams and / or creeks on their property for recreational purposes
- 19 respondents indicated that they abstracted water from dams and / or creeks on their property for irrigating crops and / or watering livestock.

Additional information gathered during the HHERA (AECOM, 2021b) field program indicated:

- bore water is connected to five properties for non-potable domestic use including toilet flushing, laundry and washing up.

2.6 Relevant legislation and government policy

The PFAS National Environmental Management Plan (NEMP) (HEPA, 2020) aims to provide governments in Australia with a consistent, practical, risk-based framework for the environmental regulation of PFAS-contaminated materials and sites. It is framed as an adaptive plan, able to respond to emerging research and knowledge.

The PFAS NEMP (2020) provides the guiding framework for the management of PFAS. For further information, see: https://www.environment.gov.au/protection/chemicals-management/pfas.

Legislation and policy instruments relevant to the development of options for PFAS management in the Management Area is set out and discussed in Appendix A.

Other key drivers and constraints impacting upon response management include, the following state instruments:

- Protection of the Environment Operations Act 1997 (POEO act)
- Contaminated Land Management Act 1997
- Environmental Planning and Assessment Act 1979
- Water Management Act 2000
- Work Health and Safety Act 2011.

Additionally, the NSW EPA has published waste classification guidance for PFOS, PFHxS and PFOA in soil (NSW EPA, 2016 – Addendum to the Waste Classification Guidelines). PFAS impacted soil that meets the requirements for General Solid Waste or Restricted Waste can be lawfully disposed at licensed landfill facilities (NSW EPA, 2016). However, there are no licensed facilities for acceptance of PFAS impacted soil that is classified as Hazardous Waste.

There are currently no liquid waste treatment facilities in NSW licensed to receive PFAS impacted liquid waste (waste code - M270) without prior treatment.

2.7 Stakeholders

A Stakeholder and Community Engagement Plan was developed to support the PFAS investigation at SMA (AECOM, 2018). Key stakeholders for the project are summarised below.

Table 2: SMA Stakeholder Groups

Stakeholder Groups	Details
Government Department and Agencies	**Commonwealth** • Department of Prime Minister and Cabinet • PFAS Task Force • Department of Health • Department of Human Services • Department of Agriculture and Water Resources • Department of Veteran Affairs • Department of the Environment and Energy • Council of Australian Governments • Australian Wine and Brandy Corporation **State** • Department of Premier and Cabinet • Department of Health • The Greater Sydney Commission • Department of Planning and Environment • Environment Protection Authority (EPA) • NSW PFAS Expert Panel • Department of Primary Industries • NSW Office of Environment and Heritage • NSW National Parks and Wildlife Service

	• Department of Family and Community Services • Rural Financial Counselling Service **Local** • Singleton Council • Cessnock City Council • Hunter Water • Hunter New England Health
Department of Defence (Internal)	Current and former personnel including: • Defence Estate and Infrastructure Group • National PFAS Investigation and Management Branch • Defence Legal Counsel • Defence Public Affairs • Singleton Military Area Personnel.
Site-specific Project Control Group	The Project Control Group (PCG) comprises of representatives from the following groups: • NSW Department of Premier & Cabinet • NSW EPA • NSW Health • NSW DPI • Singleton Council • The NSW EPA-accredited Site Auditor.
Other PFAS investigation sites	• Defence sites • Non-Defence PFAS sites. International sites and evolving investigation approaches, toxicology and remediation/management approaches.
Elected representatives	**Federal** • Senator for NSW • Minister for Defence • Minister for Defence Industry • Minister for Veterans' Affairs • Minister for Health • Minister for Aged Care • Member for Hunter, New South Wales. **State** • Premier • Minister for Health • Minister for Primary Industries • Minister for Family and Community Services • Minister for Environment • Minister for Heritage • Minister for Veterans Affairs • Member for Upper Hunter • Member for Cessnock. **Local** Singleton Shire Council:

	• Mayor, Cr Sue Moore • Councillors. City of Cessnock • Mayor, Cr Bob Pynsent • Councillors.
Traditional landowners	• Wonnarua Nation, Wonnarua Nation Aboriginal Corporation • Tribal groups in the Hunter Region: o Worimi o Kamilaroi o Wiradjuri o Darkinjung. • New South Wales Land Council.
Landholders and residents adjacent to the Base	Landholders and residents near the SMA, within or adjacent to the Investigation Area.
Businesses near the Base	Current businesses including: • Hunter Valley Wine Industry Association, Singleton Business Chamber, Singleton Chamber of Commerce • Hunter Valley Gardens • Hunter Valley wineries including: Krindlewood Vineyard, Tyrell's Wines, McGuigan Wines, Tamburlaine Organic Wines, Peter Drayton Wines, Piggs Peake Winery, Mistletoe Winery, Keith Tulloch Wine, Glandore Estate Wines, Bentwood Valley Estate • E C Throsby Pty Ltd – Livestock Buyers and Meat Exporters • Skydive Hunter Valley • Australian Army Infantry Museum • Australian Military Bank • Defence Bank • Real estate agents.
Environmental groups	• Hunter Valley Protection Alliance (HPVA) • The Conservation Volunteers (TCV) • National Conservation Council of NSW.
Community/resident groups	• National Coalition Against PFAS (CAP) • Singleton Council Sustainability Committee • Agricultural Societies Council of NSW Ltd • Rotary Club of Singleton, NSW • Newcastle Community Consultative Committee for the Environment.
Wider community	• Wider Singleton and surrounding communities/ townships • General public.
Media	• The Singleton Argus • The Newcastle Herald. Multi-media outlets: • Local newspapers at other PFAS contamination sites • The Australian and other national newspapers • ABC and commercial local and national radio and television.

To date engagement has been focused on providing timely and accurate information to:

- support stakeholders understanding of the contamination issue and investigation
- obtain information about and access to land within and surrounding the investigation area
- communicate how stakeholders can participate in the investigation or obtain further information
- understand and respond to key concerns, questions and requests
- progressively communicate the outcomes of the investigation and detail the next steps.

Defence's engagement program will continue with public notification of the digital release of the HHERA (AECOM, 2021b), DSI Addendum (2020a) and the PMAP. The HHERA (AECOM, 2021b), DSI Addendum (AECOM, 2020a) and PMAP will be made publicly available via Defence's website, and can be accessed by stakeholders to inform their understanding of potential PFAS contamination in the vicinity of SMA.

3 PMAP METHODOLOGY AND APPROACH

3.1 Overview of approach

This PMAP conforms with the PFAS NEMP (HEPA, 2020). NSW EPA and a NSW EPA-accredited Site Auditor have been consulted in the development of the PMAP.

Stakeholder engagement associated with specific response actions recommended through the development of the PMAP will be addressed as relevant in the detailed implementation documents for those actions.

The PMAP methodology steps through the following stages set out in this section.

3.2 Identify risks and consequences (Section 4)

The list of risks to be managed in this PMAP are identified as ‘elevated’ in the HHERA (AECOM, 2021b). A source / pathways / receptor analysis based on the CSM in the HHERA (AECOM, 2021b) was used to identify the relevant source (primary and secondary), pathways and receptors for the risk. For each risk, the range of potential consequences if the risk is realised have been identified.

3.3 Prepare Ongoing Monitoring Plan (Section 5)

An ongoing monitoring plan (OMP) forms a mandatory part of the PMAP and therefore it does not form a part of the options analysis.

3.4 Develop risk management options (Section 6.1)

Management option(s) were identified to address each of the risks identified in Section 4. The list of options has been informed by a range of information and research, both general and specific to the Management Area. Management Area-specific information includes:

- Risk assessments (HHERA, AECOM, 2021b), CSM (AECOM, 2021b), DSI (AECOM, 2019b) and DSI Addendum (AECOM, 2021b)
- Relevant Commonwealth and State/Territory legislation
- Feedback from stakeholder consultation
- IRM or PMAP actions undertaken or considered by Defence on other properties.

The management options include:

- the ‘do-nothing’ option. It provides the ‘base case’ against which other options are assessed, and may at times be the best available option when assessed against the criteria of ‘net environmental benefit’. It does not get assessed through this process but the potential impacts are described in the Section 4 analysis.
- Additional investigations required to address uncertainties and data gaps as identified through completion of the DSI (AECOM, 2019b) and DSI Addendum (AECOM, 2021a)
- Development of remedial action plan(s) (RAP)
- Community-level options for further assessment.

Identifying information for each option includes the objective and a description of how the objective contributes to managing the identified risk.

3.5 Detailed options analysis (Section 6.2)

For each risk, the following analysis was undertaken for each source area and each management option:

A. Cost / effectiveness / impact analysis

1 Cost range estimate
2 Effectiveness rating
3 Implementation period / timeframe
4 Potential impacts
5 Estimated net environmental benefit rating (not relevant for institutional controls).

B. Risk-based analysis

6 Proportion of action to risk
7 Best-practice status
8 Verification status
9 Technology assessment
10 Risks and mitigation
11 Key dependencies.

C. Defence implications

12 Defence capability
13 Project fit
14 Scalability.

D. Stakeholder impacts, views and consents

15 Jurisdictional regulator/s
16 Owner / occupier consents and views
17 Community.

E. Comparative analysis

Comparative analysis comparing the available options to manage an identified risk.

Details of the analysis for each of these factors are set out in Appendix D.

3.6 Integrated options analysis (Section 6.4)

Time and cost efficiencies and improved effectiveness may be found by looking for synergies between:

- other proposed PMAP response actions
- approved or proposed PMAP response actions in other Management Areas
- planned works involving infrastructure, maintenance or remediation of co-contaminants on the Defence property.

Where these synergies have been found, they are presented as an integrated package addressing the relevant sets of risks.

3.7 Recommendations analysis (Section 7.1)

The recommended set of PMAP response actions for each identified risk are based on the comparative analysis and the integrated analysis set out in Section 6.

4 IDENTIFIED RISKS AND CONSEQUENCES

4.1 Source / pathway / receptor analysis

An overview of PFAS sources, transport pathways and receptors was provided in Section 2.4. Additional information, including a detailed CSM was provided in the DSI (AECOM, 2019b) report. This CSM was further refined in the DSI addendum (AECOM, 2021a) and the HHERA (AECOM, 2021b) to accommodate for additional information. Current CSM outcomes with key elements are summarised in this section and the refined CSM is presented in **Appendix C**.

A summary of each PFAS source, transport pathway from the source and receptors is provided in the Table 3 below.

Table 3: SMA Source Area Summary

Former Cantonment Fire Station and fire training pits	
Description and risk contribution mechanism	This source area can be considered to comprise of three separate sources: 1. A source associated with its former use as a fire station and fire training pits. The DSI (AECOM, 2019b) identified widespread PFAS concentrations in soil which are consistent with historical AFFF usage across the source area. 2. A source associated with fire truck service pumps which were tested by pumping water from a large diameter well (CNN0018_GW03) located in the hardstand behind the Fire Station building. It is noted that no soil samples have been collected in the vicinity of this monitoring well, which has the highest PFAS concentrations in groundwater across the SMA. Although there is a potential for soil concentrations in this area of the former fire station to be higher than the current soil data set, they are expected to be limited in extent based on the density of sampling that has occurred. Additionally, sewage generated at the Fire Station has historically been conveyed via the wider Base sewer network to a Defence-owned pumping station at the Singleton STP located north of the Base. The DSI (AECOM, 2019b) identified PFAS was present in sewage at the pumping station, however PFAS was not detected in an additional sample collected from the pumping station during the DSI Addendum (AECOM, 2021a) indicating PFAS contributions associated with Base sewage may be intermittent. The sewage network also drains other potential PFAS source areas including the DNSDC. Depth to groundwater is greater than 4m and groundwater impacts from the Former Cantonment Fire Station are limited in extent and do not extend beyond the SMA boundary. The source area is located within Sub Catchment A (AECOM, 2019) where surface water flows are anticipated to the north (refer to **Figure F4** in **Appendix F**). Similarly, the predominant groundwater flow direction is to the north/ north-east (AECOM, 2021a). PFAS detections in surface water down gradient of this source area indicate that PFAS is being mobilised from soils and transported via surface water.

	Receptors for surface water runoff include aquatic and terrestrial ecosystems in Doughboy Hollow Creek and users of surface water in those water bodies.
Maximum PFOS + PFHxS concentrations	Soil: 3.4 milligrams per kilogram (mg/kg) Concrete: 2.31 mg/kg Surface water: 0.51 micrograms per litre (µg/L) Sediment: 0.0013 mg/kg Groundwater: 145.1 µg/L Sewage: 0.04 µg/L
Estimated volume of soil in source zone[1]	Approximately 24,000 m^3 (Assumes 1m depth)
Estimated mass of PFOS + PFHxS in soil in source zone[1]	5.3 kilograms (kg) (assumed average maximum concentration per DSI borehole of 0.122 mg/kg. The maximum concentration of 3.4 mg/kg was not used as the majority of PFOS + PFHxS impacts are considerably lower than this value and the estimate of mass within the source zone would have been overly conservative). It is noted that this estimate only takes into account the current PFAS data set and does not take into possible PFAS impacts related to the soil data gaps associated with the impacts identified in the large diameter well.
DNSDC	
Description and risk contribution mechanism	This source area is associated with historical AFFF use related to maintenance activities, emergency and ad-hoc use at the DNSDC. Anecdotally, AFFF was distributed on the ground surface as a birthday tradition and the discharge of the AFFF lines from fire trucks was tested in the creek line during maintenance. Low concentrations of PFAS in soil indicate a diffuse PFAS source. The DNSDC is located within Sub-Catchment A, detections of PFAS in surface water in the wetland area down gradient of the creek line (east of Sub-Catchment A) indicate PFAS detected in surface soils may be an ongoing source that is being transported via overland flow, in no defined drainage channel. Additionally, sewage generated at the DNSDC is conveyed via the wider Base sewer network to the Defence-owned pumping station at the Singleton STP. The DSI (AECOM, 2019b) identified PFAS was present in sewage at the pumping station, however PFAS was not detected in an additional sample collected from the pumping station during the DSI Addendum (AECOM, 2021a) indicating PFAS contributions associated with Base sewage may be intermittent. The sewage network also drains other potential PFAS source areas including the Former Cantonment Fire Station. The groundwater concentrations of PFAS recorded in this area are one order of magnitude lower than the highest concentration at the Former Fire Station which indicates AFFF usage at the DNSDC was less frequent and not as wide-spread, and is consistent with the understanding of the historic usage. Depth to groundwater is greater than 2m in the unconsolidated sand/clay and greater than 10 m in the shale. Groundwater

	impacts from the DNSDC are limited in extent and do not extend beyond the SMA boundary. Receptors for surface water runoff include aquatic and terrestrial ecosystems within dams located adjacent Army Camp Road and the ephemeral portion of Doughboy Hollow Creek and users of surface water in those water bodies.
Maximum PFOS + PFHxS concentrations	Soil: 0.0141 mg/kg Surface water: 0.51 µg/L Sediment: 0.0137 mg/kg Groundwater: 10.4 µg/L Sewage: 0.04 µg/L
Estimated volume of soil in source zone[1]	Not estimated as maximum soil concentration is <1 mg/kg
Estimated mass of PFOS + PFHxS in soil in source zone[1]	Not estimated as maximum soil concentration is <1 mg/kg
Alternate Landing Ground (ALG)	
Description and risk contribution mechanism	The ALG is a PFAS source area arising from the legacy use of AFFF associated with aircraft accidents and training emergency response activities. Soil data collected during the DSI (AECOM, 2019b) indicates that the likely source may be related to historic infrequent or minimal discharge of AFFF at the ALG during training and/or emergency response activities or via the overland flow of AFFF impacted surface water. Low soil concentrations of PFOS + PFHxS across the ALG indicate a wide-spread and diffuse PFAS source. Depth to groundwater is greater than 5m at the ALG. PFAS impacts were not reported in groundwater at the ALG. The majority of the surface water runoff from the ALG is captured within sub-catchment A (refer to **Figure F4** in **Appendix F**) and discharges off-Base via a drainage line down gradient of the ALG under Range Road. The low concentrations of PFAS detected in surface soil at the ALG have the potential to be transported by surface water during infrequent flood events. Receptors for surface water runoff include aquatic and terrestrial ecosystems in Doughboy Hollow Creek and users of surface water to the north and north east of the SMA.
Maximum PFOS + PFHxS concentrations	Soil: 0.018 mg/kg Surface water: 0.47 µg/L Sediment: Not applicable Perched groundwater: < laboratory limit of reporting (LOR)
Estimated volume of soil in source zone[1]	Not estimated as maximum soil concentration is <1 mg/kg
Estimated mass of PFOS + PFHxS in soil in source zone[1]	Not estimated as maximum soil concentration is <1 mg/kg
Dochra Airfield	
Description and risk contribution mechanism	The Dochra Airfield is a PFAS source area arising from the legacy use of AFFF associated with aircraft accidents and training emergency response activities. Soil data collected during the DSI (AECOM, 2019b) indicates that the likely source may be related to historic infrequent or minimal discharge of AFFF at the Dochra Airfield during training and/or emergency response

	activities or via the overland flow of AFFF impacted surface water. Low soil concentrations of PFOS + PFHxS across the ALG indicate a wide-spread and diffuse PFAS source. Depth to groundwater is greater than 6 m at Dochra Airfield. Groundwater impacts from Dochra Airfield are limited in extent and do not extend beyond the SMA boundary. Surface water runoff from the western side of Dochra Airfield flows into Mudies Creek and surface water runoff from the eastern side flows into Emigrant Creek. Low concentrations of PFAS were detected in one surface water sample and four sediment samples collected from Mudies Creek which indicates PFAS detected in surface soils is being transported via overland flow into Mudies Creek. PFAS was not reported in Emigrant Creek. One shallow soil sample collected directly adjacent the Dochra Airfield runway tarmac exceeded the indirect exposure soil PFOS criterion and is considered to be an outlier as the second highest concentration within this catchment is two orders of magnitude lower. It is noted that the remaining soil samples from the Mudies/Emigrant Creek catchment and the adopted soil EPC do not exceed adopted direct or indirect soil criteria and most are comparable to background concentrations. Moreover, none of the terrestrial plants and invertebrates collected within this catchment exceeded the adopted wildlife criteria. As a result, the Tier 1 assessment indicates that potential risks associated with bioaccumulation within the terrestrial ecosystem at Mudies/Emigrant Creek catchment are potentially low. Receptors for surface water runoff include aquatic and terrestrial ecosystems in Muddies Creek, Emigrants Creek and the Hunter River and users of surface water to the north and north east of the SMA.
Maximum PFOS + PFHxS concentrations[1]	Soil: 0.0035 mg/kg Sediment: 0.0004 mg/kg Surface water: 0.02 µg/L Groundwater: 0.08 µg/L
Estimated volume of soil in source zone[1]	Not estimated as maximum soil concentration is <1 mg/kg
Estimated mass of PFOS + PFHxS in soil in source zone	Not estimated as maximum soil concentration is <1 mg/kg
Helicopter Landing Ground (HLG)	
Description and risk contribution mechanism	The HLG is a PFAS source arising from the legacy use of AFFF associated with aircraft accidents and training emergency response activities. Low concentrations of PFOS + PFHxS across the area indicate a diffuse PFAS source. Surface water runoff from HLG is captured within Sub-Catchment B (refer to **Figure F4** in **Appendix F**). Surface water run-off from the HLG may be transporting low concentrations of PFAS from the ground surface through the surface water network in a south westerly direction before making its way to the north-west towards Doughboy Hollow Creek. Results from the HLG indicate that the detectable concentrations of PFAS are limited in nature and unlikely to be contributing to off-Base migration of PFAS concentrations greater than the PFAS NEMP drinking water quality guideline value (0.07 µg/L).

	Depth to groundwater is greater than 4m in HLG. Groundwater impacts from the HLG are limited in extent and do not extend beyond the SMA boundary. Receptors for surface water runoff include aquatic and terrestrial ecosystems in Doughboy Hollow Creek and users of surface water to the north and north east of the SMA.
Maximum PFOS + PFHxS concentrations[1]	Soil: 0.0367 mg/kg Surface water: 0.03 µg/L Sediment: 0.001 mg/kg Groundwater: 0.08 µg/L
Estimated volume of soil in source zone[1]	Not estimated as maximum soil concentration is <1 mg/kg
Estimated mass of PFOS + PFHxS in soil in source zone	Not estimated as maximum soil concentration is <1 mg/kg

Notes:

1 Estimates of the volume of soil and mass of PFAS have been made for on-property soil source zones where PFOS + PFHxS concentrations greater than 1 mg/kg have been reported. The volume was estimated based on data collected during the DSI (AECOM, 2019b). A soil density value of 1,800 kg/m^3 was also used. The estimates are uncertain but likely conservative.

4.2 Risk listing and consequences

This table (Table 4) summarises the potential unacceptable risks identified following the HHERA (AECOM, 2021b). Other potential risks identified in the DSI (AECOM, 2019b) and DSI Addendum (AECOM, 2021a) were assessed and found to be low and acceptable as part of the HHERA.

Table 4: Risk listing and consequences

	Risk ID	01	02	03
General	Title	**Ingestion of home-grown red meat** from sheep or cattle that have consumed water containing detectable PFAS, or have grazed in areas irrigated or flooded with water containing detectable PFAS.	**Ingestion of home-grown milk** from cows that have consumed water containing detectable PFAS, or have grazed in areas irrigated or flooded with water containing detectable PFAS.	**Cumulative ingestion of home-grown red meat, of home-grown milk** from cows from sheep or cattle and **of eggs** from home-grown backyard poultry that have consumed water containing detectable PFAS, or have grazed / roamed in areas irrigated or flooded with water containing detectable PFAS.
	Location and Extent	Off-Base Management Area	Off-Base Management Area	Off-Base Management Area
	Description	Elevated risk at the reasonable maximum exposure scenario.	Elevated risk at the reasonable maximum exposure scenario.	Elevated risk at the reasonable maximum exposure scenario.
S-P-R Linkages	Primary Sources	PFAS source areas on the SMA, in particular the Former Cantonment Fire Station and fire training pits and the DNSDC.	PFAS source areas on the SMA, in particular the Former Cantonment Fire Station and fire training pits and the DNSDC.	PFAS source areas on the SMA, in particular the Former Cantonment Fire Station and fire training pits and the DNSDC.
	Secondary Sources	Entrainment and leaching of contaminants from impacted soil and sediment sources into surface water, and subsequent surface water / groundwater interactions. Surface water and stormwater runoff. Discharge of sewage containing PFAS from the Fire Station and DNSDC via the Base sewer network to the Singleton STP.	Entrainment and leaching of contaminants from impacted soil and sediment sources into surface water, and subsequent surface water / groundwater interactions. Surface water and stormwater runoff. Discharge of sewage containing PFAS from the Fire station and DNSDC to the Singleton STP via the Base sewer line	Entrainment and leaching of contaminants from impacted soil and sediment sources into surface water, and subsequent surface water / groundwater interactions. Surface water and stormwater runoff. Discharge of sewage containing PFAS from the Fire Station and DNSDC to the Singleton STP via the sewer line which

Risk ID	01	02	03
		which conveys sewage from the Base to a Defence-owned pumping station at the Singleton STP.	conveys sewage from the Base to a Defence-owned pumping station at the Singleton STP.
Contributing Sources (off-Base)	Potential off-Base sources include the Singleton STP, the Former Council sullage tip, the Whittingham Airstrip and the Whittingham Fire Station.	Potential off-Base sources include the Singleton STP, the Former Council sullage tip, the Whittingham Airstrip and the Whittingham Fire Station.	Potential off-Base sources include the Singleton STP, the Former Council sullage tip, the Whittingham Airstrip and the Whittingham Fire Station.
Pathways	Ingestion of PFAS accumulated in home-grown livestock produce (red meat). PFAS may accumulate in animal produce via: • Direct ingestion of groundwater (or surface water) containing detectable concentrations of PFAS used for stock watering • Direct ingestion of soil where groundwater (or surface water) containing detectable concentrations of PFAS is currently or was historically used for irrigation • Ingestion of plant produce (commercial or home-grown) that may have accumulated PFAS due to the current or historic use of groundwater (or surface water) containing detectable concentrations of PFAS for irrigation and / or transfer of PFAS to soil.	Ingestion of PFAS accumulated in home-grown livestock produce (milk). PFAS may accumulate in animal produce via: • Direct ingestion of groundwater (or surface water) containing detectable concentrations of PFAS used for stock watering • Direct ingestion of soil where groundwater (or surface water) containing detectable concentrations of PFAS is currently or was historically used for irrigation • Ingestion of plant produce (commercial or home-grown) that may have accumulated PFAS due to the current or historic use of groundwater (or surface water) containing detectable concentrations of PFAS for irrigation and / or transfer of PFAS to soil.	Cumulative Ingestion of PFAS accumulated in home-grown livestock produce (red meat, milk and eggs). PFAS may accumulate in animal produce via: • Direct ingestion of groundwater (or surface water) containing detectable concentrations of PFAS used for stock watering • Direct ingestion of soil where groundwater (or surface water) containing detectable concentrations of PFAS is currently or was historically used for irrigation • Ingestion of plant produce (commercial or home-grown) that may have accumulated PFAS due to the current or historic use of groundwater (or surface water) containing detectable concentrations of PFAS for irrigation and / or transfer of PFAS to soil.
Receptors	Residents and farmers	Residents and farmers	Residents and farmers

	Risk ID	01	02	03
Consequences	Current Impacts	Has occurred. Community surveys have identified consumers of home-grown red meat.	Has occurred. Community surveys have identified consumers of home-grown milk.	Has occurred. Community surveys have identified consumers of home-grown milk and eggs.
	Potential Impacts	Potential risk of harm to human health. Potential risk from eating high quantities of locally grown red meat, which are exposed to surface water as their primary drinking water supply and/or have consumed soil or plants that have accumulated PFAS from irrigation water.	Potential risk of harm to human health. Potential risk from consuming high quantities of home-grown milk, from stock which are exposed to surface water as their primary drinking water supply and/or have consumed soil or plants that have accumulated PFAS from irrigation water.	Potential risk of harm to human health. Potential risk from consuming a combination of home-grown milk, home-grown red meat or eggs from home-grown backyard poultry that have consumed water containing detectable PFAS, or have grazed / roamed in areas irrigated or flooded with water containing detectable PFAS.
	Severity	Uncertain. Combined with other exposure pathways, this has the potential to result in overall exceedances of the tolerable daily intake (TDI). Exceeding the TDI does not mean that health effects will occur, and there is currently no conclusive evidence that exposure to PFAS will lead to health effects in humans.	Uncertain. Combined with other exposure pathways, this has the potential to result in overall exceedances of the TDI. Exceeding the TDI does not mean that health effects will occur, and there is currently no conclusive evidence that exposure to PFAS will lead to health effects in humans.	Uncertain. Combined with other exposure pathways, this has the potential to result in overall exceedances of the TDI. Exceeding the TDI does not mean that health effects will occur, and there is currently no conclusive evidence that exposure to PFAS will lead to health effects in humans.
	Temporal Risks	Ongoing contribution of PFAS from discharge of surface water from site drainage and subsequent infiltration to groundwater.	Ongoing contribution of PFAS from discharge of surface water from site drainage and subsequent infiltration to groundwater.	Ongoing contribution of PFAS from discharge of surface water from site drainage and subsequent infiltration to groundwater.

	Risk ID	01	02	03
Management	Defence	Confirm legacy AFFF products have discontinued use.	Confirm legacy AFFF products have discontinued use.	Confirm legacy AFFF products have discontinued use.
	Stakeholders	Minimise intake of home-grown red meat that have been exposed to water or soil containing detectable PFAS in the off-Base Management Area.	Minimise intake of home-grown milk that have been exposed to water or soil containing detectable PFAS in the off-Base Management Area.	Minimise intake of home-grown red meat, eggs and milk that have been exposed to water or soil containing detectable PFAS in the off-Base Management Area if consuming large quantities off all produce.

5 ONGOING MONITORING PLAN

5.1 Overview

The Management Area ongoing monitoring plan (OMP) monitors changes to surface water and groundwater contamination characteristics to inform the calibration of risk management where required.

Changes may result from the specific or cumulative impact of remediation or containment actions, existing transportation trends, changes to hydrogeology, or weather events.

The OMP for the Management Area is set out in **Attachment 1**. An OMP forms a standard component of all Defence Estate PMAPs.

5.1.1 Objective and purpose

The objective of the OMP is to provide information on changes in PFAS contamination originating from a Defence Base to inform risk management decisions by Defence and State agencies to protect human health and the environment.

Data on changes in the distribution, concentration, transport (pathways and flow rates) and transformation of the contaminants and assessment against appropriate guideline values provides:

- an evidence base for targeted and effective risk management of PFAS contamination to protect human health and environmental receptors
- an early warning that additional management of PFAS contamination may be warranted in areas not currently affected by PFAS.

5.1.2 Impacted decisions

Changes detected through the implementation of the OMP may inform a number of risk-management decisions including:

- additional investigations
- re-assessment of one or more remediation or containment actions
- additional remediation or containment actions
- changing risk management actions at receptor level (e.g. provision or cessation of alternate drinking water supplies)
- changes to State advice on types of exposure-minimisation behaviours (e.g., consumption of home produce or seafood)
- changes to State advice on boundaries of a designated management area and the management zones within
- changes or refinements to the monitoring network, frequency and parameters.

5.1.3 Related documentation

One or more specific remedial action plans (RAPs) may be developed for the Management Area. The RAP(s) (if developed) will contain specific on-going monitoring actions to assess and validate the impact of that remediation plan.

5.2 OMP communications

The following will be shared with relevant State authorities and made publicly available on the Defence website:

- OMP
- monitoring data collected during the implementation of the OMP

- decisions made in response to the data collected during implementation of the OMP
- changes to the OMP in response to incoming data over the implementation period.

5.3 OMP summary

Given that the current primary migration pathway for PFAS from the SMA is surface water, the OMP focusses monitoring efforts on this media however also considers groundwater for completeness. The OMP will include Monitoring of groundwater, surface water and sediment at, on-Site and off-Base locations within the Management Area. The locations selected for monitoring are based on results from the DSI (AECOM, 2019b) and HHERA (AECOM, 2021b) and are presented within the OMP which forms Attachment 1 of this document.

The initial implementation period of the OMP will be three years during the implementation of management measures and to establish seasonal and spatial trends through biannual and annual sampling. Following the initial implementation period, those monitoring data will be incorporated into a process to update the conceptual site model (as currently presented in the HHERA [AECOM, 2021b] and Appendix C), and an assessment of implications for off-Base impacts, and potential for exposures by human and ecological receptors. On the basis of this review, an extended implementation period of the OMP will be considered. The review will be based on the data collected including established trends, behaviour of the plume and any revision of risk. The review will address the extent of the monitoring network and the frequency of monitoring.

5.4 OMP review

The OMP will be reviewed annually in conjunction with the annual review of the PMAP, or the frequency of the review program may be tailored to site specific characteristics and the existing trend data available. The review frequency may be revised during the implementation period as more data becomes available.

6 OPTIONS IDENTIFICATION AND ANALYSIS

6.1 Options identification and analysis

6.1.1 Overview

The results of the DSI (AECOM, 2019b) and DSI Addendum (AECOM, 2021b) indicated that:

- Surface water drainage (including areas of overland flow) appear to be the current dominant transport pathways in mobilising PFAS from on-site sources to off-Base areas
- The infiltration of PFAS-impacted surface water runoff from the Cantonment and STP into the shallow alluvial deposits of Doughboy Hollow Creek via the wetland east of the STP are potentially contributing to PFAS-impacts within groundwater north and north-east of the Site. However, no direct migration pathway (i.e. no continuous plume) between PFAS impacts in groundwater at the Cantonment and groundwater impacts north of the Site was identified.

For these reasons, and until a mass flux assessment is completed, surface water migration is considered the primary pathway of migration and the subsequent options analysis will focus on this pathway to address the risks identified in **Section 4.1**.

Management options identification and analysis for the SMA focused on the following PFAS source areas:

- The Former Cantonment Fire Station
- DNSDC
- Alternate Landing Ground (ALG)
- Helicopter Landing Ground (HLG)
- Dochra Airfield.

The identification, screening, feasibility assessment, and selection of potential PFAS Management options for the identified source areas has been broadly undertaken in the following steps:

1. **Technology screening** – identification and screening assessment of potential technologies that have the capability to manage soil/ sediment and groundwater impacted by PFAS. The preferred technologies are then developed into potential management options for further evaluation.
2. **Options identification** – identification of options by source that could potentially apply to PFAS conditions at the SMA.
3. **Analysis of options** – analysis of the methodology and impacts associated with each method to establish viable management options.
4. **Comparative analysis** – a comparative assessment of the management options to assess the relative advantages and disadvantages of viable management options and identify those that should not be considered further.
5. **Integrated options analysis** – an evaluation of the effectiveness of a short list of preferred options for each source area.

This management option assessment approach is consistent with:

- Defence's guiding principles presented in Section 1.7
- The PFAS NEMP (HEPA, 2020).

6.1.2 Technology identification and screening

The identification of and screening of potentially feasible technologies was conducted in accordance with the approach presented in PFAS NEMP (2020) and Defence's PMAP approach, whereby hazard elimination is most preferred and administrative controls and use of protective equipment is least preferred.

The range of management and remediation technologies and methodologies is presented in **Table 5** below as a starting point in the development and identification of options. A screening assessment of potential management options utilising these technologies was undertaken and is detailed in Appendix E, Section E.1.

Table 5: Technology Categories

Media	In-situ	Ex-situ	Other
Solids (soils and sediments)	• Bioremediation • Chemical oxidation or reduction • Soil flushing • Soil vapour extraction • Adsorption – stabilisation/ immobilisation.	• Excavation and off-Base disposal • Bioremediation • Adsorption – solidification/ stabilisation/ immobilisation • Chemical oxidation or reduction • Soil washing/chemical extraction • Low temperature thermal desorption • High temperature thermal desorption • Pyrolysis.	• In-situ management • On-site containment in an engineered facility
Water (surface water and groundwater)	• Bioremediation • Chemical injection • Air sparging • Thermal treatment • Monitored natural attenuation • Permeable reactive barriers	• Groundwater extraction • Excavation and/ or dewatering • Extracted groundwater treatment	• Hydraulic containment

The management and remediation technology and methodologies identified in **Table 5** were then subjected to an initial screening for applicability to the remediation of PFAS contamination within the Management Area, before they were taken though to the identification of options. This screening is set out in **Appendix E, Section E1** a summary of the screening is presented in Table 6 and Table 7.

Management options identification and analysis for SMA focussed on the PFAS source areas. The treatment of groundwater outside of the source areas has not been assessed in detail for the following reasons:

1. Surface water (including sewage contributions from source areas) is currently understood to be the primary migration pathway for PFAS from the SMA
2. As noted in Section 1.6, Defence prioritises source management actions over pathway and receptor management actions (it is noted that this is not appropriate for all situations and pathway management has been considered in **Appendix E**), so far as is reasonably practicable

3. Actions to address the PFAS sources will reduce PFAS leaching to groundwater. Treatment of groundwater without first removing the sources would potentially require treatment to continue for many years (decades)
4. Groundwater is not currently known to be used for drinking water supply at SMA or in off-property areas downgradient of identified source areas. Furthermore, future use of groundwater for drinking water supply is considered unlikely given the use of rainwater tanks and the coverage of the existing mains reticulation network in the wider Management Area. NSW Health recommends that groundwater is not used for drinking, cooking and personal hygiene (including cleaning teeth and bathing) without testing and appropriate treatment including disinfection
5. Concentrations outside of the Former Cantonment Fire Training Area are relatively diffuse. Therefore, larger volumes of water are required to be treated to remove an equivalent PFAS mass. For this reason, groundwater treatment outside the source areas would have a high cost over the installation and operational periods (Category 1 cost >$13,000,000), particularly when assessing cost as dollars per gram of PFAS removed.

Table 6: Soil Treatment Technology Screening Assessment

Technology	Description[13]	Evaluation					
		Applicability	Cost Effectiveness	Timeframe	Effect on social & Ecological Values	Effect on Defence capacity	Retained of further evaluation
***In-Situ* Treatment**							
Bioremediation	The activity of naturally occurring microbes is stimulated by circulating water-based amendment solutions in-situ through contaminated soils to enhance biological degradation of organic contaminants. Amendments may be used to enhance contaminant desorption from the soils. **Technology presently not applicable to PFAS.**	X	-	-	-	-	**No**
Chemical Oxidation or Reduction	Oxidation/reduction chemically converts the hazardous contaminants to non- hazardous or less toxic compounds that are more stable, and/or inert. Oxidising/ reducing agents are commonly delivered by vertical well pressure injection. **Mostly applicable to saturated media. Technology presently not applicable for PFAS and can transform PFAS precursors into regulated PFAS (PFOS, PFOA and PFHxS).**	X	X	Med	-	-	**No**
Soil Flushing	Water or amendments (base, surfactant or chelating agent) are added to increase hydraulic gradients and 'flush' contaminants. Hydraulic control is required to capture the fluids, with ex situ treatment. **Technology not demonstrated with PFAS to date.**	X	X	-	-	-	**No**
Soil Vapour Extraction	Soil vapour is extracted and treated, thereby reducing volatile contaminant mass in unsaturated media. Can be combined with air sparging. **Technology not applicable to PFAS.**	X	-	-	-	-	**No**
Adsorption via in-situ Stabilisation / Immobilisation	Contaminants are physically bound or enclosed within a stabilised mass (solidification), or chemical reactions are induced between the stabilising agent and contaminants to reduce their mobility (stabilisation). **Cement solidification not applicable to PFAS. In-situ stabilisation not demonstrated with PFAS.**	X	X	Med	X	X	**No**

[13] Technology sources obtained from Interstate Technology Regulatory Council (ITRC) Publication Remediation Technologies and Methods for Per- and Polyfluoroalkyl Substances (PFAS), ITRC March 2018; Federal Remediation Technologies Roundtable (FRTR) Publication Remediation Technologies Screening Matrix and Reference Guide, Version 4.0.

Technology	Description[13]	Evaluation					
		Applicability	Cost Effectiveness	Timeframe	Effect on social & Ecological Values	Effect on Defence capacity	Retained of further evaluation
Ex-Situ Treatment							
Excavation and Off-Base Disposal	Commonly available soil treatment approach for categorised materials. Materials are excavated and transported to an appropriate facility for disposal. **On site pre-treatment may be required to dewater and/or dry the materials and/ or stabilise the contaminant to achieve acceptance criteria.**	√	√	Med	X	X	**Yes**
Bioremediation	Materials are excavated and treated at an on-site or off-Base facility. Dewatering of excavated materials may be required prior to treatment. Nutrients, oxygen and other amendments may be used to enhance biodegradation/ contaminant desorption from the soils via either open land-farming or in engineered 'bio-piles'. **Technology not currently applicable to PFAS.**	X	-	-	-	-	**No**
Adsorption via Stabilisation / Immobilisation	Materials are excavated and treated at an on-site or off-Base facility. Dewatering/ drying of excavated materials may be required. Contaminants are physically bound or enclosed within a stabilised mass (solidification), or chemical reactions are induced to reduce their mobility (stabilisation). **Successful small-scale application in Australia for PFAS.**	√	√	Med	X	X	**Yes**
Chemical Oxidation or Reduction	Materials are excavated and treated at an on-site or off-Base facility. Oxidation/reduction chemically converts the hazardous contaminants to nonhazardous or less toxic compounds that are more stable, and/or inert. **No proven PFAS destruction technology currently available.**	X	√	Med	X	X	**No**
Soil Washing / Chemical Extraction	Materials are excavated and treated at an on-Base or off-Base facility. Contaminants are separated from the soil in an aqueous based system. The wash water may be augmented to help remove both organics and metals. Washwater is treated and recycled. PFAS compounds are soluble, have low soil partitioning coefficients and are potentially amenable to this approach. **Technology is suitable for PFAS.**	√	X	Med	√	X	**Yes**
Low-temperature Thermal Desorption (on or off-Base)	Materials are excavated and treated at an on-Base or off-Base facility. Dewatering of excavated materials may be required prior to treatment. Wastes are heated to volatilise contaminants. A carrier gas or vacuum system transports volatilised water and organics to the gas treatment system for scrubbing/ polishing. Does not destroy PFAS mass just transfers it. **Not currently proven at scale for PFAS.**	X	-	-	-	-	**No**

Technology	Description[13]	Evaluation					
		Applicability	Cost Effectiveness	Timeframe	Effect on social & Ecological Values	Effect on Defence capacity	Retained of further evaluation
High- Temperature Thermal Desorption (on or off-Base)	Materials are excavated and treated at an on-Base or off-Base facility. Dewatering of excavated materials may be required prior to treatment. Wastes are heated to volatilise contaminants. A carrier gas or vacuum system transports volatilised water and organics to the gas treatment system for scrubbing/ polishing. **Not proven for PFAS**	X	-	-	-	-	**No**
Pyrolysis and oxidative thermal destruction (on or off-Base)	Materials are excavated and treated at an on-site or off-Base facility. Dewatering of excavated materials may be required prior to treatment. High temperatures used to volatilise water and PFAS, then combust organic constituents in hazardous wastes. Treatment of off gas and PFAS destruction by-products is required. Custom built facility would be required. **Technology is suitable for off-Base PFAS treatment.**	√	X	Long	X	X	**No**
Other							
In-Situ Management (cap/contain)	Impacted materials managed via reduction in contaminant mobility by reducing infiltration to the extent practicable and isolating impacted material. This would be achieved via a low permeability cover and sub-drainage as a contingency to control seepage. **Technology is suitable for PFAS.**	√	√	-	√	-	**Yes**
On-site containment in an engineered facility	This approach has been used in Victoria and has been implemented at RAAF Base Williamtown. On-site containment is acceptable. Involves excavation and placement in an engineered repository or containment cell that would be lined and capped. **Technology is suitable for PFAS.**	√	√	-	-	-	**Yes**

Table 7 Surface Water/Groundwater Treatment technology Screening Assessment

Technology	Description[14]	Evaluation					
		Applicability	Cost Effectiveness	Timeframe	Effect on social & Ecological Values	Effect on Defence capability	Retained for further evaluation
In-Situ Treatment							
Bioremediation	As described above for in situ biodegradation of soil/sediments. Technology not applicable to PFAS.	X	-	-	-	-	**No**
Chemical injection	Chemicals are injected into the aquifer at pre-determined dosage rate. May include oxidation/ reduction to chemically convert the hazardous contaminants to non-hazardous or less toxic compounds that are more stable, and/or inert. **No proven PFAS destruction technology currently available.**	X	X	Med	√	X	**No**
Air sparging	Air is injected into the subsurface to add oxygen and volatilise contaminants. Soil vapour is extracted and treated, thereby reducing volatile contaminant mass. **Technology not applicable to PFAS.**	X	-	-	-	-	**No**
Thermal treatment	As described above for in situ thermal treatment of soil/ sediments. **Technology not applicable to PFAS.**	X	-	-	-	-	**No**
Monitored natural attenuation	A variety of physical, chemical, or biological processes that act without human intervention to reduce the mass, toxicity, mobility, volume, or concentration of contaminants in soil or groundwater. This typically is only applicable if the primary source has been controlled, and risks can be controlled to be low and acceptable. **Technology not applicable to PFAS.**	X	-	-	-	-	**No**
Permeable reactive barriers	A permeable reactive barrier (PRB) is installed across the flow path of the groundwater contaminant plume, allowing the plume to passively pass through the wall, but the reactive media either sorbs, degrades or transforms contaminants. **Full scale application not identified.**	X	X	Long	√	√	**No**
Groundwater/Surface Water extraction	Commonly available treatment approach. Dissolved phase impacts are extracted via wells or trenches, with ex situ treatment of effluent at a water treatment plant. Treated water could be managed via reinjection or discharge. Extraction system can be designed to maximise mass removal of dissolved phase contaminants. **Requires supplementary options.**	√	X	Long	X	√	**Yes**

[14] Technology sources obtained from Interstate Technology Regulatory Council (ITRC) Publication *Remediation Technologies and Methods for Per- and Polyfluoroalkyl Substances (PFAS)*, ITRC March 2018; Federal Remediation Technologies Roundtable (FRTR) Publication *Remediation Technologies Screening Matrix and Reference Guide, Version 4.0.*

Technology	Description[14]	Evaluation: Applicability	Cost Effectiveness	Timeframe	Effect on social & Ecological Values	Effect on Defence capability	Retained for further evaluation
Excavation and/or dewatering	For shallow groundwater, bulk excavation and/or dewatering, will remove the groundwater migration pathway. Bore water would be captured and treated ex situ at a water treatment plant. Treated water could be managed via reinjection or discharge. **Technology is suitable for PFAS.**	√	√	Short	X	X	**Yes**
Extracted groundwater treatment	Groundwater treatment at a water treatment plant. A treatment train would be required, generally requiring pre-treatment to remove sediments and co-contaminants. The most common PFAS treatment is sorption. Ion exchange resins have also been utilised in a treatment train approach. Treated water could be managed via reinjection or discharge. Waste media must be treated. **Technology is suitable for PFAS.**	√	√	Short	X	√	**Yes**
Hydraulic containment	Sub-surface hydraulic barriers to affect hydraulic gradients or direct flow within the shallow system so that flow occurs laterally to drains/ sumps/ wells for extraction, or educe and retard lateral shallow groundwater flow. If combined with a low permeability cover to reduce infiltration to the shallow aquifer, there would be limited ongoing treatment of water required. **Technology is suitable for PFAS.**	√	√	Long	X	√	**Yes**
Collection of surface water from drains and sewers for treatment	Collection of PFAS impacted surface water from drains and sewers and treatment at a water treatment plant. A treatment train would be required, generally requiring pre-treatment to remove sediments and co-contaminants. The most common PFAS treatment is sorption. Ion exchange resins have also been utilised in a treatment train approach. Treated water could be managed via reinjection or discharge. Waste media must be treated. **Technology is suitable for PFAS.**	√	√	Long	X	√	**Yes**
Diversion of surface water from impacted areas or separate clean runoff	Separation of clean runoff (e.g. from roofs and unaffected areas) from PFAS impacted runoff to improve efficiency of other treatment strategies. **Technology is suitable for PFAS.**	√	√	Long	√	√	**Yes**

6.2 Management Options and Analysis

The management options include:

- the 'do-nothing' option. It provides the 'base case' against which other options are assessed in Part C and may at times be the best available option when assessed against the criteria of 'net environmental benefit'. It does not get assessed through this process but the potential impacts are described in Section 4.
- Additional investigations required to address uncertainties and data gaps as identified through completion of the DSI (AECOM, 2019b) and DSI addendum (AECOM, 2021).
- Community-level options for further assessment.

As outlined in Section 1.6, a response to a risk may involve one or more of the following three principal components:

a) source area management
b) migration pathway management
c) receptor management.

Management / remediation options have been considered for:

- sources of PFAS in soil, surface water and groundwater and their associated contribution (on-Base primary sources [Former Cantonment Fire Station, DNSDC, Dochra Airfield, the HLG and ALG) and secondary sources)
- migration pathways – on and off-Base pathways which facilitate migration of PFAS and exposure pathways (i.e. surface water and groundwater migration)
- off-Base receptors who are potentially exposed to PFAS.

The management options are summarised in **Table 8**. The 'do nothing' option will also be considered, as it provides the 'base case' against which other options are assessed.

The detailed identification and analysis of an option or set of options for each risk is set out in **Appendix E**, using the criteria set out in **Appendix D**.

Table 8 Management Options and Analysis

Source / Pathway / Receptor	Remediation / Management Options	Option No.	Risk Detail	Potential Benefit Summary Analysis: Human Health	Surface Water	Groundwater	Ecological	Economic	Social
Source									
Former Cantonment Fire Station									
Soil and Concrete	Excavation and off-Base disposal	SS-1	R01 – Ingestion of home-grown red meat R02 – Ingestion of home-grown milk R03 - Cumulative ingestion of home-grown red meat, of home-grown milk and of eggs	✓	✓	✓	✓		✓
	Adsorption via stabilisation / immobilisation	SS-2		✓	✓	✓	✓		✓
	Soil washing / chemical extraction (not applicable for concrete)	SS-3		✓	✓	✓	✓		✓
	Pyrolysis and oxidative thermal destruction (on or off-Base)	SS-4		✓	✓	✓	✓		
	In-Situ management (cap/contain)	SS-5		✓	✓	✓	✓		✓
	On-site containment in an engineered facility	SS-6		✓	✓	✓	✓		
PFAS impacted groundwater, resulting from leaching of PFAS from soil/concrete	Groundwater extraction	GS-1	Groundwater Contamination does not extend from this source beyond the SMA boundary. Therefore, limited benefit for protection of receptors.	NA.					
	Excavation and/or dewatering	GS-2							
	Extracted groundwater/surface water treatment	GS-3							
	Hydraulic containment of PFAS contaminated groundwater.	P-1							

Source / Pathway / Receptor	Remediation / Management Options	Option No.	Risk Detail	Potential Benefit Summary Analysis: Human Health	Surface Water	Groundwater	Ecological	Economic	Social
Migration of PFAS via surface water in drainage network (including Base sewage network) off-Base	Collection of surface water from drains for treatment to reduce or prevent migration of PFAS to receptors off-Base.	P-2	R01 – Ingestion of home-grown red meat R02 – Ingestion of home-grown milk R03 - Cumulative ingestion of home-grown red meat, of home-grown milk and of eggs	✓	✓		✓		✓
	Diversion of surface water from impacted areas or separate clean runoff (e.g. from roofs and unaffected areas) from PFAS impacted runoff to improve efficiency of other treatment strategies.	P-3		✓	✓		✓		✓
DNSDC									
Soil	Excavation and off-Base disposal	SS-1	R01 – Ingestion of home-grown red meat R02 – Ingestion of home-grown milk R03 - Cumulative ingestion of home-grown red meat, of home-grown milk and of eggs Maximum soil concentration of 0.0141 mg/kg is not considered reasonably practicable for management.	✓	✓	✓	✓		✓
	Adsorption via stabilisation / immobilisation	SS-2		✓	✓	✓	✓		✓
	Soil washing / chemical extraction	SS-3		✓	✓	✓	✓		✓
	Pyrolysis and oxidative thermal destruction (on or off-Base)	SS-4		✓	✓	✓	✓		
	In-Situ Management (cap/contain)	SS-5		✓	✓	✓	✓		✓
	On-site containment in an engineered facility	SS-6		✓	✓	✓	✓		
PFAS impacted groundwater, resulting from leaching of PFAS from soil.	Groundwater extraction	GS-1	Groundwater Contamination does not extend from this source beyond the SMA boundary. Therefore, limited benefit for protection of receptors.	NA.					
	Excavation and/or dewatering	GS-2							
	Extracted groundwater/surface water treatment	GS-3							
	Hydraulic containment of PFAS contaminated groundwater.	P-1							

Source / Pathway / Receptor	Remediation / Management Options	Option No.	Risk Detail	Potential Benefit Summary Analysis: Human Health	Surface Water	Groundwater	Ecological	Economic	Social
Migration of PFAS via surface water in drainage network (including Base sewage network) off-Base	Collection of surface water from drains for treatment to reduce or prevent migration of PFAS to receptors off-Base.	P-2	R01 – Ingestion of home-grown red meat R02 – Ingestion of home-grown milk R03 - Cumulative ingestion of home-grown red meat, of home-grown milk and of eggs	✓	✓		✓		✓
	Diversion of surface water from impacted areas or separate clean runoff (e.g. from roofs and unaffected areas) from PFAS impacted runoff to improve efficiency of other treatment strategies.	P-3		✓	✓		✓		✓
ALG									
Soil	Excavation and Off-Base Disposal	SS-1	R01 – Ingestion of home-grown red meat R02 – Ingestion of home-grown milk R03 - Cumulative ingestion of home-grown red meat, of home-grown milk and of eggs Maximum soil concentration of 0.018 mg/kg is not considered reasonably practicable for management.	✓			✓		
	Adsorption via stabilisation / immobilisation	SS-2		✓			✓		
	Soil washing / chemical extraction	SS-3		✓			✓		
	Pyrolysis and oxidative thermal destruction (on or off-Base)	SS-4		✓			✓		
	In-Situ Management (cap/contain)	SS-5		✓			✓		
	On-site containment in an engineered facility	SS-6		✓			✓		
PFAS impacted groundwater, resulting from leaching of PFAS from soil.	Groundwater extraction	GS-1	Groundwater contamination was not reported at this source.	NA.					
	Excavation and/or dewatering	GS-2							
	Extracted groundwater/surface water treatment	GS-3							
	Hydraulic containment of PFAS contaminated groundwater.	P-1							

Source / Pathway / Receptor	Remediation / Management Options	Option No.	Risk Detail	Potential Benefit Summary Analysis: Human Health	Surface Water	Groundwater	Ecological	Economic	Social
Migration of PFAS via surface water in drainage network off-Base	Collection of surface water from drains for treatment to reduce or prevent migration of PFAS to receptors off-Base.	P-2	R01 – Ingestion of home-grown red meat R02 – Ingestion of home-grown milk R03 - Cumulative ingestion of home-grown red meat, of home-grown milk and of eggs	✓	✓		✓		✓
	Diversion of surface water from impacted areas or separate clean runoff (e.g. from roofs and unaffected areas) from PFAS impacted runoff to improve efficiency of other treatment strategies.	P-3		✓	✓		✓		✓
HLG									
Soil	Excavation and off-Base disposal	SS-1	R01 – Ingestion of home-grown red meat R02 – Ingestion of home-grown milk R03 - Cumulative ingestion of home-grown red meat, of home-grown milk and of eggs Maximum soil concentration of 0.0367 mg/kg is not considered reasonably practicable for management.	✓			✓		
	Adsorption via stabilisation / immobilisation	SS-2		✓			✓		
	Soil washing / chemical extraction	SS-3		✓			✓		
	Pyrolysis and oxidative thermal destruction (on or off-Base)	SS-4		✓			✓		
	In-Situ Management (cap/contain)	SS-5		✓			✓		
	On-site containment in an engineered facility	SS-6		✓			✓		
PFAS impacted groundwater, resulting from leaching of PFAS from soil.	Groundwater extraction	GS-1	Groundwater contamination does not extend from this source beyond the SMA boundary. Therefore, limited benefit for the protection of receptors. A maximum groundwater concentration of 0.08 µg/L is not considered reasonably practicable for management.	NA.					
	Excavation and/or dewatering	GS-2							
	Extracted groundwater/surface water treatment	GS-3							
	Hydraulic containment of PFAS contaminated groundwater.	P-1							

Source / Pathway / Receptor	Remediation / Management Options	Option No.	Risk Detail	Potential Benefit Summary Analysis: Human Health	Surface Water	Groundwater	Ecological	Economic	Social
Migration of PFAS via surface water in drainage network off-Base	Collection of surface water from drains for treatment to reduce or prevent migration of PFAS to receptors off-Base.	P-2	R01 – Ingestion of home-grown red meat R02 – Ingestion of home-grown milk R03 - Cumulative ingestion of home-grown red meat, of home-grown milk and of eggs Maximum surface water concentration of 0.03 µg/L is not considered reasonably practicable for management.	✓	✓		✓		✓
	Diversion of surface water from impacted areas or separate clean runoff (e.g. from roofs and unaffected areas) from PFAS impacted runoff to improve efficiency of other treatment strategies.	P-3		✓	✓		✓		✓
Dochra Airfield									
Soil	Excavation and off-Base disposal	SS-1	R01 – Ingestion of home-grown red meat R02 – Ingestion of home-grown milk R03 - Cumulative ingestion of home-grown red meat, of home-grown milk and of eggs Maximum soil concentration of 0.0035 mg/kg is not considered reasonably practicable for management.	✓			✓		
	Adsorption via stabilisation / immobilisation	SS-2		✓			✓		
	Soil washing / chemical extraction	SS-3		✓			✓		
	Pyrolysis and oxidative thermal destruction (on or off-Base)	SS-4		✓			✓		
	In-situ management (cap/contain)	SS-5		✓			✓		
	On-site containment in an engineered facility	SS-6		✓			✓		
PFAS impacted groundwater, resulting from leaching of PFAS from soil.	Groundwater extraction	GS-1	Groundwater Contamination does not extend from this source beyond the SMA boundary. Therefore, limited benefit for the protection of receptors. A maximum groundwater concentration of 0.08 µg/L is not considered reasonably practicable for management.	NA.					
	Excavation and/or dewatering	GS-2							
	Extracted groundwater/surface water treatment	GS-3							
	Hydraulic containment of PFAS contaminated groundwater.	P-1							

<table>
<tr><th rowspan="2">Source / Pathway / Receptor</th><th rowspan="2">Remediation / Management Options</th><th rowspan="2">Option No.</th><th rowspan="2">Risk Detail</th><th colspan="6">Potential Benefit Summary Analysis</th></tr>
<tr><th>Human Health</th><th>Surface Water</th><th>Groundwater</th><th>Ecological</th><th>Economic</th><th>Social</th></tr>
<tr><td rowspan="2">Migration of PFAS via surface water in drainage network off-Base</td><td>Collection of surface water from drains for treatment to reduce or prevent migration of PFAS to receptors off-Base.</td><td>P-2</td><td rowspan="2">R01 – Ingestion of home-grown red meat
R02 – Ingestion of home-grown milk
R03 – Cumulative ingestion of home-grown red meat, of home-grown milk and of eggs
Maximum surface water concentration of 0.02 µg/L is not considered reasonably practicable for management.</td><td>✓</td><td>✓</td><td></td><td>✓</td><td></td><td>✓</td></tr>
<tr><td>Diversion of surface water from impacted areas or separate clean runoff (e.g. from roofs and unaffected areas) from PFAS impacted runoff to improve efficiency of other treatment strategies.</td><td>P-3</td><td>✓</td><td>✓</td><td></td><td>✓</td><td></td><td>✓</td></tr>
</table>

6.3 Comparative analysis

Subsequent to the technology screening, potential management options were developed for detailed feasibility evaluation and comparative analysis. The options were formulated to combine management, engineering and administrative controls (rather than just a specific technology) to meet the PMAP framework. As the HHERA (AECOM, 2021b) identified risks to receptors (refer Section 1.5), management actions to reduce these risks are required and as such, the “do nothing” approach has not been considered further.

The management options are conceptually described in Table 6 and comprise primary source control and secondary source control, pathway management and receptor administrative controls. The potential management options were evaluated against the assessment criteria presented in Appendix D.

The results of the comparative analysis were used to develop the management option evaluation (refer to Table 9) that could be considered for each of the source areas contributing to the potentially elevated risks. They have been assessed on their relative risk reduction benefit - level of risk reduction likely to be achieved relative to implementation effort (based on technical, logistical and financial considerations). The detailed identification and analysis of an option for each source is set out in Appendix E-2.

Based on the comparative analysis and assessment, while acknowledging that the primary source has been eliminated (legacy AFFF is no longer in use at the SMA) and will require monitoring of measurable outcomes to assess improvements in the receiving environment, source area management and implementation of receptor controls are the preferred management options that are likely to provide the most significant environmental benefits to manage the potentially elevated risks identified for the Base.

Table 9 Comparative Analysis

Option No.	Title	Overall Assessment of Remediation / Management			Justification	Potential Applicability to Source Area				
		Further Consideration Warranted	Further Consideration may be Warranted	Further Consideration Unlikely to be Warranted		Former Cantonment Fire Station	DNSDC	HLG	Dochra Airfield	ALG
SS-1	Excavation and off-Base disposal		✓		Does not meet best practice status, limited landfills in NSW accepting PFAS waste. Community likely to accept option.	✓	X PFAS concentrations in soil are unlikely to warrant management.	X PFAS concentrations in soil are unlikely to warrant management.	X PFAS concentrations in soil are unlikely to warrant management.	X PFAS concentrations in soil are unlikely to warrant management.
SS-2	adsorption via stabilisation / immobilisation		✓		Only small-scale application proven in Australia, community likely to accept option. Likely to have positive overall environmental benefits.	✓	X PFAS concentrations in soil are unlikely to warrant management.	X PFAS concentrations in soil are unlikely to warrant management.	X PFAS concentrations in soil are unlikely to warrant management.	X PFAS concentrations in soil are unlikely to warrant management.
SS-3	Soil washing / chemical extraction			✓	Potentially suitable for the remediation of PFAS contaminated soil, likely to be more optimal in sandy soils. Likely to have greater benefit with greater PFAS concentrations, at low concentrations unlikely to provide value for money. Community likely to accept option. Technology is scalable. Likely to have positive overall environmental benefits.	X	X	X	X	X
SS-4	Pyrolysis and oxidative thermal destruction (on or off-Base)			✓	There is currently no suitable thermal treatment facility licensed to receive PFAS impacted waste in New South Wales. On-Site treatment is possible though would require a purpose-built plant requiring long lead times for design, construction and permitting.	X	X	X	X	X
SS-5	In-situ management (capping layer)	✓			Can generally be quickly implemented at source areas, relatively low cost, provides isolation of impacts from pathways. Likely to have positive overall environmental benefits.	✓	X PFAS concentrations in soil are unlikely to warrant management.	X PFAS concentrations in soil are unlikely to warrant management.	X PFAS concentrations in soil are unlikely to warrant management.	X PFAS concentrations in soil are unlikely to warrant management.
SS-6	On-site containment in an engineered facility	✓			Can be scaled to accept waste from multiple source areas. Likely to have positive overall environmental benefits.	✓	X PFAS concentrations in soil are unlikely to warrant management.	X PFAS concentrations in soil are unlikely to warrant management.	X PFAS concentrations in soil are unlikely to warrant management.	X PFAS concentrations in soil are unlikely to warrant management.

Option No.	Title	Overall Assessment of Remediation / Management			Justification	Potential Applicability to Source Area				
		Further Consideration Warranted	Further Consideration may be Warranted	Further Consideration Unlikely to be Warranted		Former Cantonment Fire Station	DNSDC	HLG	Dochra Airfield	ALG
P-2	Collection of surface water from drains and collection of sewage from sewer lines (Fire Station and DNSDC only) for treatment		✓		Technology is currently implemented at other bases and addresses the primary risk to receptors. Unless source areas are managed, capture and treatment would be required indefinitely. The source areas at the SMA lie within large catchments, requiring the construction of large detention basins would to capture event flows. Consideration may be warranted in the future. Community likely to accept option. Likely to have positive overall environmental benefits.	While it is possible to implement pathway management at each on-Base source area, due to the cost of water treatment plants and that they must be continuously operational, the nature of the risks identified in Section 4.2 and the ephemeral nature of the drains and overland flow, pathway management has been assessed for implementation on a whole of Base approach (with discharge points assessed as Northern discharge point from the Base towards Doughboy Hollow Creek, the southern discharge point from the Base towards Doughboy Hollow Creek and the sewer line rather than for individual source areas.				
P-3	Diversion of surface water from impacted areas or separate clean runoff		✓		Does not treat contaminated water, however, may improve efficiency/effectiveness of surface water treatment. Community likely to accept option.					
A-1	Ongoing community engagement and reinforcement of NSW Government precautionary advice to reduce or prevent PFAS exposure.	✓			Ongoing community engagement is considered ‘best-practice’ as it involves providing up-to date information to the community on precautionary advice. Compliments other management actions. This option is noted to be a commitment of the OMP.	Receptors of the risks identified in Section 4.2 are not present at the individual source areas. Therefore, this management option has been assessed for the whole of Management Area.				

6.4 Integrated options analysis outcomes

The integrated options analysis outcomes (**Table 10**) identifies the elevated risks that can be managed through implementation of the preferred risk management options. The analysis demonstrates how the preferred management options aim to concurrently reduce multiple elevated risks. It is important to note that the implementation of risk management options will not immediately negate some risks (i.e. following implementation of source or pathway management options, it is likely to take some time until off-Base PFAS concentrations reduce to acceptable levels), however, it is anticipated that off-Base PFAS concentrations and associated potential risks will progressively reduce with time.

Additionally, there may be opportunities to integrate other Base projects with the management strategy, for example; if development or infrastructure upgrades were proposed or nearby any of the identified source areas, this may present an opportunity to utilise the development works to achieve remedial outcomes such as excavation or surface capping of impacted soils.

Due to the similarities in risk profile, the ALG, HLG and Dochra Airfield have been combined in **Table 10** below.

Table 10 Integrated Options Analysis for each PMAP Source Area

Management Options	Technical Applicability	Logistical, Defence and Stakeholder Considerations	Financial Considerations	Relative Risk Reduction Benefit
Former Cantonment Fire Station				
Preferred Management Option – Source Management (Data Gap Investigation) –The Former Cantonment Fire Station has relatively unimpeded access to the PFAS impacts (i.e. there is no critical infrastructure to Base operations present). The greatest PFAS impacts were generally found in the samples collected from the surface (0.0 to 0.01 m below grounds surface [bgs]) or 0.5 m bgs. Low level PFAS impacts (maximum concentrations reported in the DSI of between 0.01 mg/kg and 0.5 mg/kg) which generally did not exceed the adopted human health and ecological criteria, were found over an area of approximately 24,000 m^2. A maximum concentration of 3.4 mg/kg was reported by GHD, 2012 within close vicinity of the fire station. There is potential for a source associated with the large diameter well (CNN0018_GW03) located in the hardstand behind the Fire Station building, where soil concentrations may be higher, than the current soil data set. The extent of impacts are expected to be limited in extent based on the density of sampling undertaken during the DSI. Due to the widespread low level impacts at this source area, there is potential for ongoing leaching of PFAS to surface water and groundwater and as such it is recommended that a data gap investigation be carried out, including rainfall simulation and the installation of lysimeters to estimate the contribution of this source to PFAS concentrations at surface water discharge points from the Base. Depending on the outcomes of the data gap investigation, a Remedial Action Plan (RAP) may be developed for the Source Area. If an RAP is required, it should consider the source associated with the large diameter well (CNN0018_GW03), the RAP should further consider but not be limited to placement of a capping layer. In combination with the data gap investigation a mass flux study should be undertaken to better understand the on-going contribution of PFAS from the SMA and its source areas to the environment via surface water and groundwater. PFAS impacted concrete identified during the DSI is recommended to be removed and appropriately disposed to a licensed landfill. Pathway management through the use of a water treatment plant is a supplementary option which is not presently recommended to manage the discharge of surface water off-Base primarily due to the diffuse PFAS concentrations likely to be generated and the ephemeral nature of surface water bodies. During high flow events, it is unlikely to be practical to capture the majority of runoff for treatment. Update of health and safety procedures to include appropriate Personal Protective Equipment (PPE) for maintenance workers, if not already in place. Ongoing monitoring will assess changes to PFAS concentrations in groundwater and surface water over time prior to or following any implemented management actions.				
Source Control	A capping layer is technically feasible for the Former Cantonment Fire Station and addresses the primary pathway of surface water migration.	Unlikely to affect Defence capability. Likely to be acceptable to all stakeholders.	A capping layer would be comparatively inexpensive compared to other source remediation options. If the cost for implementing a cap is at the lower end of the cost range estimate (which is likely) (refer to **Appendix E**), then consideration is warranted, even when the uncertainty in how it will reduce PFAS concentrations in Doughboy Hollow Creek is taken into account.	A capping layer will be effective at reducing PFAS migrating from the source area however it is unknown to what extent it may contribute to reducing PFAS concentrations in Doughboy Hollow Creek, if at all.
Pathway Management	Unless source areas are managed, capture and treatment will be required indefinitely. The design of any water treatment system would be complex so as to account for the large variations in flow conditions. The ephemeral nature of surface water bodies would require large catchment systems to be constructed, for relatively diffuse PFAS concentrations which may not be acceptable nor a commensurate course of action as it may not provide a net environmental benefit nor represent value for money option to Defence. Additionally, during high flow events, it is unlikely to be practical to capture the majority of runoff.	Success of management dependent on source control and therefore would not be considered on its own. Unlikely to affect Defence capability. Unlikely to be acceptable to all stakeholders as a management option in isolation. May be acceptable in combination with source control.	Likely to require substantial capital expenditure coupled with additional ongoing operation and maintenance expenditure.	Low – Surface water concentrations are less than PFAS NEMP recreational water criteria at appropriate discharge points from the Base. The option will remove PFAS mass from the pathway, however, it is unknown to what extent it will contribute to reducing PFAS concentrations overall in Doughboy Hollow Creek. Any water treatment plant design would need to balance the risk reduction benefit against the cost and practicality of installation.

Management Options	Technical Applicability	Logistical, Defence and Stakeholder Considerations	Financial Considerations	Relative Risk Reduction Benefit
Exposure (Receptor) Control	Ongoing community engagement and reinforcement of NSW Government precautionary advice to reduce or prevent PFAS exposure is considered appropriate.	Administrative control is an acceptable approach.	Insignificant direct costs.	This option does not remove/isolate impacted material from the source or receiving environment, so no relative risk reduction is achieved. However, minimising exposure via receptor control would present human exposure reduction benefits.
DNSDC Compound				
Preferred Management Option – Source Management (review existing work plans and provide advice for the management of PFAS if encountered during the SMA Mid Term Refresh) – The DNSDC compound had relatively low maximum soil concentrations reported during the DSI, with a maximum PFOS + PFHxS concentration of 0.0141 mg/kg. As such soil concentrations are unlikely to warrant management. It is noted that no soil data was collected in the immediate vicinity of monitoring well CNN0039_GW02 which reported the maximum groundwater concentration at the DNSDC of 10.42 µg/L. It is also noted that the concrete hard stand was not assessed for leaching during the DSI. Down gradient surface water concentrations indicate that PFAS is mobilising from the source, with a maximum PFOS + PFHxS concentration of 0.51 µg/L reported. Part of the DNSDC compound is planned to be demolished during 2021 as part of the SMA Mid Term Refresh. As such, it is prudent this program of works is better understood before any remedial activities are planned. Appropriate guidance should be provided to the SMA Mid Term Refresh project on the management of PFAS. A mass flux study, including evaluating soil concentrations in the vicinity of CNN0039_GW02 and the concrete hard stand, should be undertaken to better understand the on-going contribution of PFAS from the SMA and its source areas to the environment via surface water and groundwater. Ongoing monitoring will assess changes to PFAS concentrations in groundwater and surface water over time.				
Source Control (not currently recommended)	Either excavation or placement into a containment cell or cap/containment in-situ is technically feasible for the DNSDC but is not recommended until existing work plans are reviewed.	Unlikely to affect Defence capability. Likely to be acceptable to all stakeholders.	Given the low concentrations in soil the cost of source control is not likely to be proportionate to the risk reduction benefit.	Low, given the low soil concentrations identified.
Pathway Management	Unless source areas are managed, capture and treatment will be required indefinitely. The design of any water treatment system would be complex so as to account for the large variations in flow conditions. The ephemeral nature of surface water bodies would require large catchment systems to be constructed, for relatively diffuse PFAS concentrations which may not be acceptable nor a commensurate course of action as it may not provide a net environmental benefit nor represent value for money option to Defence. Additionally, during high flow events, it is unlikely to be practical to capture the majority of runoff.	Success of management dependent on source control and therefore would not be considered on its own. Moderate impact to Defence capability, as land will be required for water treatment plants which could otherwise be used for Defence capability. Unlikely to be acceptable to all stakeholders as a management option in isolation. May be acceptable in combination with source control.	Likely to be very costly capital expenditure with additional ongoing operation and maintenance expenditure.	Low – Surface water concentrations are less than the PFAS NEMP recreational water criteria at appropriate discharge points from the Base. The option will remove PFAS mass from the pathway, however it is unknown to what extent it will contribute to reducing PFAS concentrations overall in Doughboy Hollow Creek. Any water treatment plant design would need to balance the risk reduction benefit against the cost and practicality of installation.
Exposure (Receptor) Control	Ongoing community engagement and reinforcement of NSW Government precautionary advice to reduce or prevent PFAS exposure is considered appropriate.	Administrative control is an acceptable approach.	Insignificant direct costs.	This option does not remove/isolate impacted material from the source or receiving environment, so no relative risk reduction is achieved. However, minimising exposure via receptor control would present human exposure reduction benefits.

<table>
<tr><th>Management Options</th><th>Technical Applicability</th><th>Logistical, Defence and Stakeholder Considerations</th><th>Financial Considerations</th><th>Relative Risk Reduction Benefit</th></tr>
<tr><td colspan="5">Alternate Landing Ground, Helicopter Landing Ground and Dochra Airfield</td></tr>
<tr><td colspan="5"><u>Preferred Management Option – Review outcomes of other management options and implement administrative controls</u>
Due to the relatively low PFAS concentrations reported in multiple media at the Alternate Landing Ground, the Helicopter Landing Ground and the Dochra Airfield, active remediation and/or management is not considered to be required at this time. Management actions at other source areas (Former Cantonment Fire Station and the DNSDC Compound) should be implemented and a mass flux study be completed to better understand the on-going contribution of PFAS from the SMA and its source areas to the environment. The mass flux study can be used to inform the requirement for management at these diffuse source areas.
Ongoing monitoring will assess changes to PFAS concentrations in groundwater and surface water over time.</td></tr>
<tr><td>Source Control</td><td>Excavation and/ or cap/containment in-situ is technically feasible for individual sources. However, given the relatively low PFAS concentrations in multiple media and the large spatial extent of the low-level impacts it is not considered feasible.</td><td>May affect Defence capability during remediation works.</td><td>High capital expenditure.</td><td>Low relative risk reduction benefit for the expenditure incurred.</td></tr>
<tr><td>Exposure (Receptor) Control</td><td>Ongoing community engagement and reinforcement of NSW Government precautionary advice to reduce or prevent PFAS exposure is considered appropriate.</td><td>Administrative control is an acceptable approach.</td><td>Insignificant direct costs.</td><td>This option does not remove/isolate impacted material from the source or receiving environment, so no relative risk reduction is achieved. However, minimising exposure via receptor control would present human exposure reduction benefits.</td></tr>
</table>

7 CONCLUSION

7.1 Recommended PMAP response actions

Based on the options analysis undertaken for this PMAP, the following actions are recommended:

1. **Data Gap Investigation at the Former Cantonment Fire Station**. The data gap investigation should consider the use of rainfall simulation and the installation of lysimeters to estimate the quantum and significance of contribution of this source to PFAS concentrations in surface water at the Base boundary.
2. **Review the works planned at the DNSDC as part of the SMA Mid Term Refresh**. Part of the DNSDC compound is planned to be demolished during 2021 as part of the SMA Mid Term Refresh. As such, it is prudent this program of works is better understood before any remedial activities are planned. Appropriate guidance should be provided to the SMA Mid Term Refresh project on the appropriate management of PFAS.
3. **Undertake a Mass Flux Study**. A mass flux study should be undertaken to understand the on-going contribution of PFAS from the SMA and its source areas to the environment via partitioning of PFAS from soil to water and via surface water drainage and groundwater.
4. **Implement the OMP** to monitor changes in PFAS concentrations within the Management Area, both in groundwater, in wastewater discharge and in surface water bodies that ultimately drain to the Hunter River and regional groundwater. Undertake community consultation as part of the OMP.
5. **Work with NSW Government and other stakeholders to evaluate the significance of current data gaps**. This assessment would focus on groundwater impacts above the health based guidance values in the north eastern part of the Management Area as identified during the DSI Addendum (AECOM, 2021a) and understand the contribution of PFAS from the Singleton STP.

7.2 PMAP implementation

The timeframes for implementation of this PMAP will be informed by a risk-based approach that provides fiscally responsible use of public resources. Key factors include:

Priority for PFAS migration and human health	Priority accorded under the Defence PFAS Response Management Strategy to implementing practicable solutions to prevent or minimise the migration of PFAS beyond the Defence property boundary; and measures to protect the community from exposure while management actions addressing source areas and/or migration pathways are underway.
Priority for higher risks	Priority given to relatively higher risks within one or more Management Areas.
Response actions underway	Response actions already underway, having commenced during the site investigations phase to manage a risk identified as requiring early intervention.
Co-dependent actions	Whether the implementation of one response action is dependent on the implementation of another response action.
Use of public resources	Defence's obligations under the Commonwealth Procurement Rules (issued under the *Public Governance, Performance and Accountability Act 2013*) to achieve value for money in

	procurement; and to use public money in an efficient, effective, economical and ethical manner. Cost-effectiveness may be facilitated through: • grouping the implementation of similar response actions within one or more Management Areas • aligning Defence infrastructure and maintenance plans with a recommended response action.
Public Works Committee	Timeframes for approvals and notification processes under the *Public Works Committee Act 1969* for medium and larger public works.

Priority of response actions may change over the life of the PMAP based on a range of variables including:

- the outcomes of earlier PMAP response actions
- the development of relevant legislation, policy, guidelines and whole-of-government positioning
- changes in land use surrounding the SMA
- feedback received from stakeholders
- the availability of new relevant science and technology
- changes in timeframes for approvals (e.g. PWC) and procurement processes.

7.3 Timeframes for Response Actions

Primary implementation period

- Short term: within first 12 months:
  - Data Gap Investigation at the Former Cantonment Fire Station
  - Review the works planned at the DNSDC as part of the SMA Mid Term Refresh
  - Commence a Mass Flux Study
  - Initiate the OMP.
- Medium term: within the first three years
  - Publication of Data Gap investigation at the Former Cantonment Fire Station and subsequent RAP development (if required)
  - DNSDC Mid Term Refresh completed
  - Publication of Mass Flux Study and subsequent RAP development (if required).

Extended implementation period

- Long term: beyond three years. These activities will commence in year 1 but will be delivered across the extended implementation:
  - OMP implementation
  - Annual PMAP review
  - Implementation of RAP (if required).

7.4 Review and update

This PMAP (including the OMP) has been developed based on existing knowledge, current government policy settings, and available scientific methodologies and technology. PFAS management is a field that is rapidly evolving.

Defence will review and update (where necessary) the PMAP at intervals of 12 months to ensure that the document is current and its recommendations are valid.

Performance measures for individual response actions under this PMAP will be contained in the relevant approval or procurement documentation.

An earlier review/update may be triggered where circumstances demand it. Examples of circumstances that may trigger a review/update include:

- a performance evaluation of specific PMAP response actions that recommends changes or advises that its objectives are not being met
- updated information obtained from PMAP response actions involving further investigations or data from the Ongoing Monitoring Plan
- feedback and information received as a result of the on-going community and/or stakeholder consultation
- any significant changes of land use which may occur in the area within the Management Area or adjoining land
- changes in legislation, policy and guidelines/standards that could have a direct bearing on the project
- changes to Defence’s strategic approach to managing PFAS contamination
- on-going research and development of management/remediation technologies to address PFAS impacted soil and groundwater
- changes to water supply options available to land owners and residents in the area surrounding the SMA
- progress in risk management and remediation activities that may require realignment or further calibration
- new scientific findings that update the knowledge or assumptions underlying the PMAP or specific PMAP response actions
- any other new information that has the potential to positively or negatively impact the objectives of the PMAP.

Any proposed changes to this PMAP will be communicated and discussed with the community and key stakeholders including Federal and State government agencies and the local Council.

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APPENDIX A: Regulatory and policy analysis

Appendix A supplements section 2.6 (Relevant legislation and government policy).

This Appendix identifies relevant legislation, policy, guidance and standards applicable to the development and prioritisation of management options for the Management Area. It further identifies key drivers and constraints affecting that development and/or prioritisation.

A1 Commonwealth legislation, policy and standards

A1.1 Outline

The following Commonwealth legislation and policy is relevant to the risk management of the Management Area:

Commonwealth legislation

Environment Protection and Biodiversity Conservation Act 1999

Under the EPBC Act, any activity which is likely to have a significant impact on the environment, or on matters of national environmental significance, requires the approval of the Commonwealth Minister for the Environment and Energy. Under the Act, 'environment' is defined broadly and includes, but is not limited to, ecosystems and their constituent parts, people and communities, natural and physical resources and the heritage values of places. Non-compliance can result in penalties for both individuals and the organisation.

National Environment Protection (Assessment of Site Contamination) Measure 1999, as amended 2013

National Environment Protection Measures (NEPM) are developed by the National Environment Protection Council to establish a nationally consistent approach to the assessment of site contamination and ensure sound contamination assessment practices.

NEPM The *National Environment Protection Measures (Implementation) Act 1998* (the Implementation Act) gives the Australian Government the power to implement NEPM on its own land and for its own activities.

Work Health and Safety Act 2011

Relevant to general health and safety compliance relating to all works associated with the risk management of the Management Area. Defence operates within the Commonwealth WHS jurisdiction however the WHS Act will need to be considered for all aspects of the response management actions undertaken in off-Base areas.

Commonwealth policy, standards and guidance

<u>Defence policy, standards and guidance</u>

- Defence Environmental Policy
- Defence Estate Strategy 2016-2036
- Defence Environmental Strategy 2016-2036
- Defence Construction and Maintenance Framework 2018
- Defence PFAS Response Management Strategy 2018
- Defence Interim Response Management Guidelines 2018
- Defence PMAP Template and Guidance 2018
- Defence PFAS Applied Research Strategy 2018

<u>Commonwealth whole-of-government policy, standards and guidance</u>

- Intergovernmental Agreement on a National Framework for Responding to PFAS Contamination 20 February 2018
- PFAS National Environmental Management Plan 2020 (NEMP)
- The Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZG, 2018)
- Final Health Based Guidance Values (HBGV) for PFAS for use in site investigations in Australia, FSANZ February 2017
- Guidance on Per and Polyfluoroalkyl (PFAS) in Recreational Water, National Health and Medical Research Council (2019)

A1.2 Key institutional drivers and constraints impacting on development/prioritisation of options

Currently there is limited Commonwealth legislation on the designation of waste disposal criteria. The PFAS NEMP provides criteria to be adopted at the State level and in 2016 NSW EPA has issued an Addendum to the Waste Classification Guidelines (2014) – Part 1: classification of PFAS for disposal as ‘General Solid Waste’ and ‘Restricted Solid Waste’. Although the waste guidelines have been released, there are limited number of landfills that will accept PFAS impacted solids.

The PFAS NEMP document outlines the preferred framework for PFAS management including containment, remediation, treatment and disposal. The document acknowledges that each site is unique, and any management response must consider site-specific conditions in determining the best approach to the management of PFAS. Overall, the document presents the hierarchy of options for site clean-up hierarchy, namely; treatment and reuse on–site is preferred to treatment and reuse offsite, while long-term containment off-Base is least preferred.

A2 State/Territory Legislation and Policy

A2.1 Outline

Protection of the Environment Operations Act 1997

The *Protection of the Environment Operations Act 1997* (POEO Act) is administered by the NSW EPA. It prohibits any person to cause pollution of waters, or air and provide penalties for air, water and noise pollution offences.

The POEO Act would need to be considered for activities that involve off-Base actions, including discharge of treated water.

Contaminated Land Management Act 1997

The *Contaminated Land Management Act 1997* aims to promote the better management of contaminated land. The objects of this Act are to establish a process for investigating and (where appropriate) remediating land areas where contamination presents a significant risk of harm to human health or some factor of the environment.

The NSW EPA has powers to respond to contamination that is causing significant risk of harm to human health or the environment. The NSW EPA can direct land owners to investigate or remediate contaminated land and requires land owners to report contamination where there is a significant risk of harm (Duty to Report). This Act may be triggered if contamination migrates beyond Commonwealth boundaries.

A.2.2 Key institutional drivers and constraints impacting on development/prioritisation of options

SEPP 55

Under SEPP 55, a Development Consent will be required if the proposed remediation work (eg, installation of an off-Base treatment plant) is considered as a Category 1 work, it will require Development Consent (likely from Council) and may also be classified as Designated Development which would require the preparation of an Environmental Impact Statement to accompany the development application.

However, if the proposed work is considered to be a Category 2 work under SEPP 55, it does not require Development Consent but the local authority (Council) must be notified of the proposed work 30 days before it can be commenced.

It is likely that because of the nature and scale of some of the proposed response management works conducted off-Base, some level of authorisation would also be required regardless of whether SEPP 55 formed the basis of justification for the proposed works.

Environmental Planning and Assessment Act 1979

The *Environmental Planning and Assessment Act 1979* aims to promote the social and economic welfare of the community and a better environment by the proper management, development and conservation of the State's natural and other resources. The act also aims to protect the environment, including the conservation of threatened and other species of native animals and plants, ecological communities and their habitats. The act requires the relevant planning authority to take into consideration the impacts to the environment (both natural and built) and the community of the proposed development and/or land-use change.

A3.2 Key drivers and constraints impacting on development/prioritisation of options

Development Consent timelines would need to be considered for the options, in particular for implementation of off-Base treatment facility infrastructure.

APPENDIX B: Interim response management analysis

This Appendix is a placeholder where Interim Response Management (IRM) actions relevant to the Management Area are detailed.

No IRM have been identified for the SMA.

APPENDIX C Source – pathway – receptor analysis

Where the following sections refer to an Investigation Area (IA), this is as defined in the HHERA, (AECOM, 2021b). Graphical illustrations of the CSM in presented on **Figure 5** and **6** in **Appendix F**.

1. Sources

The following activities on or near the SMA are considered to have resulted in PFAS detections in environmental media:

On-Site

- Historical AFFF use and storage associated with training at the former Cantonment fire station
- Historical AFFF use associated with maintenance activities, emergency response and *ad hoc* use at the DNSDC Compound
- Historical AFFF use associated with aircraft accidents and training emergency response activities at the ALG
- Historical AFFF use associated with aircraft accidents and training emergency response activities at Dochra Airfield
- Historical AFFF use associated with aircraft accidents and training emergency response activities at the HLG.

Off-Base

- Singleton Sewage Treatment Plant (STP)
- Former Council sullage tip (potential source)
- Whittingham Airstrip (potential source
- Whittingham Fire Station (potential source
- Hunter Valley Mines Rescue Facility
- Fire and Rescue NSW, Singleton Station (potential source
- Anecdotal evidence of vehicle incidents on the highway surrounding the Base (potential source)
- Coal mine operations (potential source)
- NSW Rural Fire Service (potential source)

2. Contaminant Transport Mechanisms

PFAS are moderately to highly soluble, depending on the individual PFAS chemical structure and can be readily dissolved / leached by infiltrating rainwater, groundwater or surface water.

As discussed within the DSI (AECOM, 2019b) and DSI Addendum (AECOM, 2021a), the following migration mechanisms may have contributed to the transport of PFAS from the site:

- Shallow soil samples near the Cantonment boundary: the likely source of PFAS in these soil samples is surface water migration via drainage lines which leave sub-catchment A of the SMA or overland flow of PFAS impacted surface water during times of flooding
- Surface water and sediment locations near the Cantonment boundary: the likely source of PFAS is surface water migration via drainage lines which leave sub-catchment A of the SMA or overland flow of PFAS impacted surface water during times of flooding
- Shallow soil samples and surface water and sediment samples further from the SMA boundary: off-Base sources are likely to be contributing to these detections
- Groundwater samples: off-Base sources are likely to be contributing to these detections.

The DSI (AECOM, 2019b) concluded that PFAS detections at residential properties within the off-Base Investigation Area are likely related to both on-site sources, dominantly through surface water transport following high rainfall events and associated overland flow, and off-Base sources within the Investigation Area including the Singleton STP. The DSI Addendum (AECOM, 2021a) included additional sampling to further support this understanding.

3. Potential Human Receptors

Taking into account the current and future use of the off-Base Investigation Area and the scope of the HHRA (AECOM, 2021b), the potential human receptors identified within the off-Base Investigation Area are:

- residents (including adults, children and infants)
- recreational users of waterways on private property. It is assumed that the assessment of recreational users is also protective of infrequent visitors to the area
- outdoor workers, either on private property (e.g. agriculture, grounds maintenance) or on public land (e.g. utilities maintenance).

4. Potentially Complete Human Exposure Pathways

When a potentially complete exposure pathway from source to receptor is identified, the next step is to undertake a risk assessment to evaluate the potential for exposure to exceed tolerable levels.

The exposure scenario for each receptor have been identified as follows:

- Residential: activities that typically occur within the boundaries of a residential property, such as gardening, cleaning, backyard recreation, ingestion of home-grown eggs / vegetables / red meat / milk from the property
- Recreational (surface water): activities that typically occur in waterways on a residential property, such as swimming, because there are no publicly accessible waterbodies that can be used for recreational purposes within the off-Base Investigation Area. Recreational fishing in surface water bodies on residential properties was not identified as a current pathway. However, the intake from direct contact pathways (dermal contact and incidental ingestion of water) during recreational fishing activities is likely to be less than the intake during swimming
- Outdoor worker: activities typically undertaken by agricultural workers on residential properties or utility maintenance workers along roadways. This includes activities that a casual employee at a commercial horticultural / agricultural enterprise may undertake during a work-day such as irrigation and land management (e.g. cultivation or excavation of soils). The assessment of this receptor does not include the standard residential pathways previously mentioned
- Council worker: activities that an employee of the Council or a utility / service provider may carry out in the off-Base Investigation Area during a work-day such as maintenance of service pits (which extend below the groundwater table) and surface water drainage networks.

Where a person falls into more than one group (for example, a person that may work as an agricultural worker who also resides in the off-Base Investigation Area), the cumulative exposure can be evaluated by combining the exposure estimates from the applicable scenarios that relate to their personal circumstances.

In addition to the above exposure scenarios, it is noted that there is the potential for a number of pathways that are currently not complete to be present in the future, such as exposure to abstracted groundwater to be used in the future for drinking-water. Because these pathways have not been identified to currently be occurring, they have not been considered in this CSM.

A number of registered and unregistered groundwater bores were identified across the off-Base Investigation Area. Based on the available information from Water Use Survey (WUS) and interviews with the residents as part of the field sampling program groundwater within the off-Base Investigation

Area is not used as a drinking water source. The majority of residents reported to be connected to town water supply and / or use rainwater tanks for their domestic supply.

The data available at the time of preparing this report did not identity residents who consume home-raised or wild animal products, yabbies or home-raised poultry. Inclusion of these pathways was considered outside the scope of this CSM and have not been considered further.

APPENDIX D Options analysis criteria

This Appendix sets out the criteria for the detailed options analysis.

Cost / effectiveness / impact analysis

1	**Cost range estimate**	Estimate a cost range for implementation of the option, accompanied by an explanation of the basis of that estimate. The cost ranges below have overlapping values: this is to avoid a scenario where a borderline cost may distort the analysis. Where a cost estimate falls into an overlapping range, but effectiveness of the option in item 2 is assessed as ‘high’, use the lower cost range to adjust the margin of error in favour of the ‘effectiveness’ criterion.		
		Category 1	PWC approval required above $15 million.[15]	> $13,000,000
		Category 2	Medium works notification to PWC required above $2 million	> $1,500,000 < $15,000,000
		Category 3	Project actions	> $450,000 < $2,000,000
		Category 4	Community level actions[16]	< $500,000
		Cost ranges should include direct, indirect, recurrent costs and the costs of mitigating any secondary risks identified in item 10 below. Where there will be a need for ongoing operations, management, maintenance and monitoring beyond the Primary Implementation Period, a separate risk should be identified and a separate options analysis applied.		
2	**Effectiveness rating**	Assign an effectiveness rating in accordance with the following criteria:		
		High	The option is projected to meet all its objectives or meet a ‘best available’ standard	
		High with supplementary option	The option, together with a supplementary option, is projected to meet all its objectives or meet a ‘best available’ standard	
		Medium	The option is projected to make significant progress towards meeting its objectives.	
		Medium with supplementary option	The option, together with a supplementary option, is projected to make significant progress towards meeting its objectives	
		Low	The option cannot reliably be projected to make significant progress towards meeting its objectives or may only do so in a timeframe that is not aligned with effective management of the identified risk.	

[15] http://www.defence.gov.au/estatemanagement/governance/Committees/pwc/Default.asp

[16] Accommodates a range of community level response actions such as arranging alternative grazing for impacted agricultural businesses or providing fencing. The value of community-level actions may also exceed $500,000.

3	**Implementation period / timeframe**	Designate an indicative timeframe for implementation: Primary implementation period – Short term: 1-12 months from the date of the PMAP – Medium term: 1-3 years Extended implementation period – Long term: beyond 3 years. Where an action extends across both the primary and extended implementation period, both should be designated. Different procurement actions may apply.
4	**Potential impacts**	List any potential environmental and socio-economic impacts (positive and negative). Negative impacts should be further analysed and addressed in item 10 below.
5	**Estimated net environmental benefit**	Whether the impacted environment as a whole would experience a net benefit. Rate as negative / neutral / marginal / moderate / significant. For an institutional or administrative control, this item may be deleted or rated as N/A. This factor does not require a detailed analysis. Rather, it requires an informed estimate. For example, the draining of an important wetland to remove the PFAS would be likely to result in negative net environmental benefit for biota and be unacceptable to environmental regulators and the community.

Risk-based analysis

6	**Proportion of action to risk**	Assess the scale (timing/implementation logistics/impact on Defence capability) and cost of the action in comparison to the likelihood and scale of the risk.
7	**Best-practice status**	Consider whether there is a recognised 'best-practice' standard available for the category of the proposed solution and whether the solution meets a relevant standard.
8	**Verification status**	Where an action involves a remediation technology, provide information on the verification status.
9	**Technology assessment**	Where an option involves a remediation technology: – infrastructure and energy requirements – ability to construct and operating technology – reliability of technology – ability to monitor effectiveness – ability to obtain any necessary approvals – availability of services and materials

10	**Risks and mitigation**	List primary, secondary[17] and residual[18] risks of implementation and associated mitigation options, such as: – potential environmental impacts, including PFAS transference, cross-contamination, and remobilisation; and presence of contaminants other than PFAS – the availability of treatment/storage management options to manage waste streams – impact on existing infrastructure (including bores) – potential social and economic impacts (e.g. land use or employment.) Specify whether mitigation options form a part the same option or whether they are developed separately (provide option identification number).
11	**Key Dependencies**	List any key dependencies, including the implementation of any other options, and any external factors.

Defence implications

12	**Defence capability**	The extent to which an aspect of Defence capability will be impacted by the process or outcome of implementation of the option and the availability and cost of alternatives (consultations with Defence)
13	**Project fit**	Whether the project outcomes complement the outcomes of response management actions for the same or other sites (consultations with Defence)
14	**Scalability**	Whether the outcomes of the project can be scaled up or down to address similar needs in the same or other Bases.

Stakeholder impacts, views and consents

15	**Jurisdictional regulator/s**	List jurisdictional authorisations required to implement the option. Note the views of any relevant jurisdictional regulator
16	**Owner / occupier consents and views**	List any owner / occupier consents required to implement the option. Note the views of any relevant landowner or occupier.
17	**Community**	Defence's understanding of the views of the impacted community.

[17] Secondary risks are risks that emerge from implementation of a risk management response

[18] Residual risks comprise that component of the identified risk that is not addressed by the option.

APPENDIX E Options listing and analysis

This Appendix provides the analysis of the management options identified as available to address the range of risks identified in the DSI (AECOM, 2019b), the DSI Addendum (AECOM, 2021a) and risk assessments (HHERA, AECOM, 2021b). Risk management includes the application of remediation technology and methodologies; pathway management; as well as institutional and administrative controls and advisories.

Part E1 sets out the range of remediation technology and methodologies with an initial screening for applicability to the remediation of PFAS contamination within the Management Area.

Part E2 constitutes the detailed options analysis for the identified risks.

A comparative analysis is provided in Section 6.2 and the consideration of integrated options is provided in Section 6.3.

E1 PFAS remediation options screening[19]

E1.1 Solids (Soil/Sediment)[1]

Description	Technical applicability	Lifecycle costs	Relative cost	Timeframe	Social and environmental values	Impact – Defence capability / service delivery	Further consideration
In-Situ Treatment - solids							
Bioremediation The activity of naturally occurring microbes is stimulated by circulating water-based amendment solutions in-situ through contaminated soils to enhance biological degradation of organic contaminants. Amendments may be used to enhance contaminant desorption from the soils. Most applicable to saturated media.	Not applicable to PFAS. Emerging technology (laboratory scale only).	-	-	-	-		No
Chemical Oxidation or Reduction Oxidation/reduction chemically converts the hazardous contaminants to non- hazardous or less toxic compounds that are more stable, and/or inert. Oxidising/reducing agents most commonly used are Fentons reagent, permanganate, hydrogen peroxide and other propriety destruction formulations. Chemical commonly delivered by vertical well pressure injection. Delivery issues with contact of reagent with affected media. Most applicable to saturated media.	Emerging technology (laboratory scale only although field pilots are underway where a catalysts are being used to improve effectiveness). However, no proven PFAS destruction technology currently available.	Chemical injection is commonly conducted in-situ in Australia (last 10 years). Significant chemical volumes and multiple applications would be required.	High (largely due to high chemical costs and large area of application)	12 to 24 months for application	-		No
Soil Flushing	Full scale in situ application has not	Hydraulic control would be required					No

[19] Based on RAAF Base East Sale PFAS Management Area Plan prepared by Senversa, August 2018. Senversa sourced its technologies from ITRC publication, *Remediation Technologies and Methods for Per- and Polyfluoroalkyl Substances (PFAS),* ITRC March 2018; and PFAS National Environment Management Plan, Australian and New Zealand Heads of EPA (HEPA), January 2018 and Federal Remediation Technology Roundtable (FRTR) screening matrix (https://frtr.gov/matrix2/top_page.html).

Description	Technical applicability	Lifecycle costs	Relative cost	Timeframe	Social and environmental values	Impact – Defence capability / service delivery	Further consideration
Water or amendments (base, surfactant or chelating agent) are added to increase hydraulic gradients and 'flush' contaminants via advective pore flushing, desorption and diffusion gradients from impacted materials. Hydraulic control is required to capture the fluids, with ex situ treatment. PFAS compounds are soluble and have low soil partitioning coefficients, and are potentially amenable to this approach. However, low level concentrations are expected to be persistent due to desorption and matrix diffusion.	been identified in Australia.	but would be difficult to achieve – there is a risk of increasing hazards via groundwater migration exposure pathways where shallow groundwater is present.					
Soil Vapour Extraction Soil vapour is extracted and treated, thereby reducing volatile contaminant mass in unsaturated media. Can be combined with air sparging.	Not applicable to PFAS – PFAS are non- or low volatility.						No
Adsorption - In-situ Stabilisation/Immobilisation Contaminants are physically bound or enclosed within a stabilised mass (solidification), or chemical reactions are induced between the stabilising agent and contaminants to reduce their mobility (stabilisation). Potential additives (stabilisation/binding) include carbon, RemBind or MatCARE. Cement solidification not applicable due to PFAS leachability under alkaline conditions.	Only one full scale in situ application has been identified in Australia. Soil materials were stabilized and then placed in lined landfill. Solidification is not applicable to PFAS.	Chemical injection and soil mixing is commonly conducted in-situ in Australia (last 10 years). Limited full scale in situ application has been identified in Australia. Can require up to 25% v/v amendment addition to achieve stabilisation.	Moderate to high (largely due to high amendment costs and large area of application)		Concern that some amendments also bind up carbon required to sustain plant and animal life.		No
Ex-Situ Treatment - solids							
Excavation and Off-Base Disposal Commonly available soil treatment approach for categorised materials. Materials are excavated and transported to an appropriate facility for disposal.	Excavation and dewatering/drying of materials is technically feasible. Off-Base disposal of material classified as	Dependent on disposal options	High (Largely due to disposal costs and transport)	12 months	Off-Base disposal is considered the least desirable approach to managing contaminated soils on the PFAS NEMP waste hierarchy.	Significantly disruptive to operations.	Yes

Description	Technical applicability	Lifecycle costs	Relative cost	Timeframe	Social and environmental values	Impact – Defence capability / service delivery	Further consideration
On site pre-treatment may be required to dewater and/or dry the materials prior to offsite transport and disposal.	hazardous waste would not be permitted.				Interstate transport to an off-Base facility would require authorisation from each state.		
Bioremediation Materials are excavated and treated via biodegradation at an on-site or off-Base facility. Dewatering of excavated materials may be required prior to treatment. The activity of naturally occurring microbes is stimulated by circulating water-based solutions through contaminated soils to enhance biological degradation of organic contaminants. Nutrients, oxygen and other amendments may be used to enhance biodegradation / contaminant desorption from the soils via either open land-farming or in engineered 'bio-piles'.	Not applicable for PFAS. Emerging technology (laboratory scale only).						No
Adsorption - Solidification/ Stabilisation/ Immobilisation Materials are excavated and treated at an on-site or off-Base facility. Dewatering/drying of excavated materials may be required prior to treatment. Additives are added to excavated soils in a mixing plant. Contaminants are physically bound or enclosed within a stabilised mass (solidification), or chemical reactions are induced between the stabilising agent and contaminants to reduce their mobility (stabilisation). A combination of soil mixing with selective additives (stabilisation/binding) has been applied to PFAS impacted soils/sediments on a relatively small scale successfully in Australia. Potential additives (stabilisation/binding) include activated carbon, modified clay or combined clay and activated carbon (e.g. RemBind or MatCARE). Cement stabilisation not applicable due to PFAS leachability under alkaline conditions.	Applicable	Applicable. Soil mixing required to ensure adequate contact with impacted media. Can require up to 25% v/v amendment addition to achieve stabilisation	Moderate	12+ months. Validation of stabilisation may take 6 months.	Treatment and reuse of contaminated soil is considered high on the PFAS NEMP and EPA's waste hierarchy. Significant chemical use would be required.	Significant disruption to operations	Yes – not likely as a stand-alone solution but potential to be coupled with off-Base disposal, on-site retention or as part of in-situ management options

Description	Technical applicability	Lifecycle costs	Relative cost	Timeframe	Social and environmental values	Impact – Defence capability / service delivery	Further consideration
Treated materials would be reused at site. However, the potential for very low levels of leachability mean siting and cover of the material must still be considered.							
Chemical Oxidation or Reduction Materials are excavated and treated at an on-site or off-Base facility. Chemicals are added to excavated soils via mixing in a batching plant or stockpiles. Oxidation/reduction chemically converts the hazardous contaminants to nonhazardous or less toxic compounds that are more stable, and/or inert. Oxidising/reducing agents most commonly used are Fentons reagent, permanganate, hydrogen peroxide and other propriety destruction formulations.	Emerging technology (laboratory scale only). However, no proven PFAS destruction technology currently available.	Applicable. Soil mixing requirements to consider to ensure adequate contact with affected media. Geotechnical suitability of treated material (i.e. a slurry) for site retention needs consideration.	Moderate to high (largely due to high chemical costs)	12+ months with material handling on-site	Treatment and reuse of contaminated soil is considered high on EPA's waste hierarchy. Significant chemical use would be required.	Some disruption to operations	No
Soil Washing / Chemical Extraction Materials are excavated and treated at an on-site or off-Base facility. Contaminants sorbed onto soil particles are separated from the soil in an aqueous based system. The wash water may be augmented with a basic leaching agent, surfactant, pH adjustment or chelating agent to help remove both organics and metals. PFAS compounds are soluble and have low soil partitioning coefficients, and are potentially amenable to this approach. However, low level concentrations in leachate are expected to be persistent, requiring significant treatment	One full scale application has been identified in Australia. Likely to increase intensiveness of treatment for clay rich soils (i.e. increased number of washing events for reduced mass removal).	Treatment of multiple waste streams (water, sludge concentrate) required. Geotechnical suitability of treated material (i.e. graded materials) for site retention needs consideration.	Moderate to high (potentially due to waste stream management and processing time)	12+ months with material handling on-site	Treatment and reuse of contaminated soil is considered high on the PFAS NEMP and EPA's waste hierarchy.	Plant requires large footprint.	No
Low-temperature Thermal Desorption (on or off-Base) Materials are excavated and treated at an on-site or off-Base facility. Dewatering of excavated materials may be required prior to treatment.	Limited pilot scale research for PFAS (+1,100°C required for destruction and/or long residence time) Vapour stream treatment will	-	-	-	-	-	No

Description	Technical applicability	Lifecycle costs	Relative cost	Timeframe	Social and environmental values	Impact – Defence capability / service delivery	Further consideration
Wastes are heated to 93°C to 315°C to volatilise water and organic contaminants. A carrier gas or vacuum system transports volatilised water and organics to the gas treatment system for scrubbing/polishing.	be required – air emission by-products not yet established.						
High- Temperature Thermal Desorption (on or off-Base) Materials are excavated and treated at an on-site or off-Base facility. Dewatering of excavated materials may be required prior to treatment. Wastes are heated to 315°C to 538°C to volatilise water and organic contaminants. A carrier gas or vacuum system transports volatilised water and organics to the gas treatment system for scrubbing/polishing.	Not proven for PFAS (+1,100°C required for destruction and/or long residence time, with vapour stream treatment required)	-	-	-	-	-	No
Pyrolysis and oxidative thermal destruction (on or off-Base) Materials are excavated and treated at an on-site or off-Base facility. Dewatering of excavated materials may be required prior to treatment. High temperatures 870°C to 1,200°C used to volatilise water and PFAS, then combust (in the presence of oxygen) organic constituents in hazardous wastes. Treatment of off gas and PFAS destruction by-products is required. These may include hydrofluorine and sulphuric acids. Incomplete combustion products may include carbon monoxide, carbonyl difluoride, sulphur	Applicable, although air emission by-products not well established.	Only feasible for PFAS at high temperatures. Off gas treatment required. Most feasible if transported to an existing off-Base facility.	Very high (due to treatment costs)	4 to 5 years.	High energy use and consideration for potential destruction by-products and incomplete combustion products is required.	Significant disruption to operations	No
Other - solids							
In-situ management Impacted materials managed via reduction in contaminant mobility by reducing infiltration to the extent practicable, and isolating impacted material.	Applicable In-situ management is acceptable where conducted in an environmental audit	Applicable	Low	Depends on project staging and auditor.	In-situ management of soil is considered to be high on the PFAS NEMP's waste hierarchy and avoids transport of materials		Yes

Description	Technical applicability	Lifecycle costs	Relative cost	Timeframe	Social and environmental values	Impact – Defence capability / service delivery	Further consideration
This would be achieved via a low permeability cover and sub-drainage as a contingency to control seepage (if any).	and risks are demonstrated to be low and acceptable.				off-Base so is therefore considered more sustainable than placement in an off-Base facility. Manages issue while technologies are developing. Ability to review treatment practicability in future with known location of wastes.		
On-site containment in an engineered facility This approach has been used in Victoria and Tasmania. On-site containment is acceptable. Involves excavation and placement in an engineered repository or containment cell that would be lined and capped.	Applicable In-situ management is acceptable where conducted in an environmental audit and risks are demonstrated to be low and acceptable. Requires suitable location for the facility.	Applicable	Low	Depends on project staging and auditor.	On-site containment is lower on the waste hierarchy as the process involves construction of an engineered facility. This avoids transport of materials offsite so is considered more sustainable than placement in an off-Base facility.	Depending upon source area, low to significant disruption to operations	Yes

E1.2 Waters (Surface water and groundwater)

Description	Technical applicability	Lifecycle costs	Cost effectiveness (relative cost)	Timeframe	Social and environmental values	Impact – Defence capability / service delivery	Further consideration
In-Situ Treatment – groundwater							
Bioremediation As described above for in situ biodegradation of soil/sediments.	Not applicable to PFAS. Emerging technology (laboratory scale only).	-	-	-	-		No

Description	Technical applicability	Lifecycle costs	Cost effectiveness (relative cost)	Timeframe	Social and environmental values	Impact – Defence capability / service delivery	Further consideration
Chemical Injection Chemicals are injected into the aquifer at pre-determined dosage rate. May include oxidation/reduction to chemically convert the hazardous contaminants to non-hazardous or less toxic compounds that are more stable, and/or inert. Other options may include novel additives such as slurried activated carbon which is a binding technology.	Emerging technology (laboratory scale only). However, no proven PFAS destruction technology currently available.	Chemical injection (oxidant) is commonly conducted in-situ in Australia (last 10 years). Significant chemical volumes would be required.	High (largely due to chemical costs and application)	12 to 24 months	In-situ treatment is considered high on EPA's waste hierarchy.	Some disruption to operations	No
Air Sparging Air is injected into the subsurface to add oxygen and oxidise contaminants. Soil vapour is extracted and treated, thereby reducing volatile contaminant mass.	Not applicable to PFAS – non- or low volatility.	-	-	-	--	-	No
Thermal Treatment As described above for in situ thermal treatment of soil/sediments.	Not applicable to PFAS.	-	-	-	-	-	No
Monitored Natural Attenuation A variety of physical, chemical, or biological processes that, under favourable conditions, act without human intervention to reduce the mass, toxicity, mobility, volume, or concentration of contaminants in soil or groundwater. This typically is only applicable if the primary source has been controlled, and risks are demonstrated to be, or can be controlled to be, low and acceptable.	Not applicable to PFAS – there is limited natural attenuation in the environment.	-	-	-	-	-	No
Permeable Reactive Barriers A permeable reactive barrier (PRB) is installed across the flow path of the groundwater contaminant plume, allowing the plume to passively pass through the wall, but the reactive media either sorbs, degrades or transforms contaminants. Common reactive media include zero valent iron, natural zeolites and organic substrates. Recent research has assessed use of PRBs to promote effective enzyme- optimized humification reactions to treat PFAS.	Potentially applicable as a component of an overall strategy. However, no full scale and/or long-term application for PFAS identified in Australia or globally. Expected to be applicable in short	Reactive media can require replacement (depending on sorptive capacity and concentrations being treated) and disposal/treatment.	Moderate to High (Depends on size, reactive media to be used, replacement of media)	Long term operation	In-situ treatment is considered high on the PFAS NEMP and EPA's waste hierarchy.	Depending on source area, low to significant disruption to operations.	No

Description	Technical applicability	Lifecycle costs	Cost effectiveness (relative cost)	Timeframe	Social and environmental values	Impact – Defence capability / service delivery	Further consideration
PRBs can either be configured as a continuous wall to intersect the plume, or as a funnel-and-gate system with low permeability walls that direct groundwater flow through reactive media in a 'gate'.	term for some hydrogeological settings.						
Ex-Situ Treatment – groundwater							
Groundwater extraction Commonly available treatment approach. Dissolved phase impacts are extracted via a series of wells or trenches ('French drains'), with ex situ treatment of effluent at a water treatment plant. Treated water could be managed via reinjection or discharge. Extraction system can be designed to maximise mass removal of dissolved phase contaminants, though this approach is typically more suited for hydraulic control purposes (see below).	Not applicable as a stand-alone option – is not likely to be practicable to address secondary sources (e.g. PFAS sorbed to soils). Desorption and back diffusion of contaminants from the formation can limit the ability to reach low-level management goals and cause extended treatment timeframes.	Requires water treatment (See below). Applicable as a component of an overall management strategy.	Moderate capital cost, but high lifecycle cost due to long duration	1+ years, long term operation	Considered low on hierarchy when used in isolation but can be a component of overall site strategy	Low to some disruption to operations.	No
Excavation and/or dewatering For shallow groundwater, bulk excavation and dewatering, or just dewatering, of these materials will remove the groundwater migration pathway. Porewater would be captured and treated ex situ at a water treatment plant. Treated water could be managed via reinjection or discharge. Excavated soil (where bulk excavation and dewatering) would be subject to disposal to an off-Base landfill or on-site containment cell or in situ management (see above for soils/sediment). If materials are left in situ, cover would be required to optimise recharge of the fill materials.	Applicable	Requires water treatment (See below). Applicable as a component of an overall management strategy.	Low to moderate	6 to 12 months.	Disposal considered energy intensive and low on EPA's waste hierarchy.	Significant disruption (excavation) and increased risk of subsidence if dewatering alone.	Yes, but only as part of an overall management alternative.
Extracted groundwater treatment For the above groundwater extraction options, ex situ treatment at a water treatment plant is required. A treatment train would be required, generally requiring:	Applicable Treatment technologies are commercially available and have	Applicable A pilot trial and treatment train approach may be	Moderate	See for above options	See for above options	Little disruption to operations	No

Description	Technical applicability	Lifecycle costs	Cost effectiveness (relative cost)	Timeframe	Social and environmental values	Impact – Defence capability / service delivery	Further consideration
• Pre-treatment to remove sediments and co-contaminants. This may include sand filtration, flocculation, sorption. • PFAS removal via sorption, ultrafiltration (nanofiltration), foam fractionation, or reverse osmosis. The most common PFAS treatment is sorption using granular activated carbon (GAC) and/or ultrafiltration (e.g. reverse osmosis). Other media sorptive media include modified clays (e.g. sand MatCARE). Ion exchange resins have also been optimized in a treatment train approach. Emerging technologies being studied include plasma, sonochemical treatment, photochemical oxidation and thermally- induced reduction. Treated water could be managed via reinjection or discharge. Waste media must be treated (e.g. incineration) to destroy PFAS, or disposed of at landfill.	been used for PFAS water treatment in Australia (in particular GAC, and to a lesser extent ultrafiltration and ion exchange).	required depending on water quality and co-contaminants. A method to manage waste media is required (see above for soil/sediment options for disposal, on site containment or in situ management)					
Other – water							
Hydraulic containment Sub-surface hydraulic barriers consist of a series of vertically installed walls, or excavated trenches near the perimeter of shallow water impacts, to: • Affect hydraulic gradients or direct flow within the shallow system so that flow occurs laterally to drains/sumps/wells for extraction; and/or • Reduce and retard lateral shallow groundwater flow. If no measures are implemented to reduce infiltration, will require ongoing water extraction and treatment, and does not reduce management requirements. If combined with a low permeability cover to reduce infiltration to the shallow aquifer, there would be limited ongoing treatment of water required.	Applicable but difficult, given that there are multiple water bearing units at and near the SMA that may require treatment at different depths. Extraction potential may be limited from aquifer units with low yield and high clay content in alluvium / colluvium.	Applicable Requires water treatment (See above). Would only be feasible if combined with a strategy to reduce infiltration to the perched aquifer (e.g. a low permeability cover).	Low to moderate	Ongoing	Considered energy intensive and low on EPA's waste hierarchy, but system can be optimised to reduce O&M costs.	Little disruption to operations, but combined with a low permeability cover system would result in significant disruption to operations.	No

Description	Technical applicability	Lifecycle costs	Cost effectiveness (relative cost)	Timeframe	Social and environmental values	Impact – Defence capability / service delivery	Further consideration
Surface water collection and treatment PFAS impacted surface water can be collected and treated. The treatment train would generally require: • Pre-treatment to remove sediments and co-contaminants. This may include sand filtration, flocculation, sorption. • PFAS removal via sorption, ultrafiltration (nanofiltration), foam fractionation, or reverse osmosis. The most common PFAS treatment is sorption using granular activated carbon (GAC) and/or ultrafiltration (e.g. reverse osmosis). Other media sorptive media include modified clays (e.g. sand MatCARE). Ion exchange resins have also been optimized in a treatment train approach. Emerging technologies being studied include sonochemical treatment, photochemical oxidation and thermally- induced reduction. Treated water could be managed via discharge. Waste media must be treated (e.g. incineration) to destroy PFAS, or disposed of at landfill.	Treatment technologies are commercially available and have been used for PFAS water treatment in Australia (in particular GAC, and to a lesser extent ultrafiltration and ion exchange). Surface water flows are more highly variable than groundwater flows. Collection and storage requirements may impact feasibility.	Applicable A pilot trial and treatment train approach may be required depending on water quality and co-contaminants. A method to manage waste media is required (see above for soil/sediment options for disposal, on site containment or in situ management)	Moderate	Long term operation	Considered low on hierarchy when used in isolation but can be a component of overall site strategy	Little disruption to operations	Yes

E2 Options listing and detailed options analysis

E2.1 Former Cantonment Fire Station

No #	**SS-1**
Title (functional)	Excavation and Off-Base Disposal.
Description	Excavation of impacted fill and natural soils and sediments at the Former Cantonment Fire Station, to the extent practicable, and either on-site storage (pending treatment at a future date) or off-Base disposal (at a facility licensed to receive the waste).
Objective	Removal of PFAS contaminated soil to reduce leaching of PFAS into groundwater and surface water, and therefore reduce the mass of PFAS migrating to groundwater and surface water.
How this objective contributes to managing the identified risk	By removing PFAS mass from the source area, migration of PFAS from the source area via surface water will likely be reduced. This may in turn reduce migration of PFAS off-Base to Doughboy Hollow Creek. (down gradient). By reducing PFAS concentrations migrating in surface water, this option may go some way to addressing: - R01 – Ingestion of home-grown red meat - R02 – Ingestion of home-grown milk - R03 – Cumulative ingestion of home-grown red meat, of home-grown milk and of eggs
The extent to which this option is expected to meet the ob9jective	Expected to contribute to meeting the objective of reducing PFAS mass flux from source areas. The extent that this is able to be achieved will be related to volume and concentration of PFAS impacted soil that is removed. Excavation around the fire station building may present risk to the structural integrity of the building and this may prevent removal of all PFAS impacts (greater impacts have been identified close to the building footprint). Operational, access and logistical constraints are anticipated, in particular where infrastructure /buildings are present. Aligns with remediation / management hierarchy – i.e. remediation / management of source areas is preferred over pathways or receptors.
Whether the option addresses – source, – pathway – receptor, and/or – extended implementation period requirements	This option addresses the source and the pathway of PFAS contamination, by removing the PFAS impacted soil and thereby preventing it from leaching / migrating to groundwater and surface water.
Supplementary / complementary options	- Additional investigations to refine the source area for excavation (as required) will be required prior to works commencing. - P-2 - Surface water treatment - P-3 - Diversion of surface water from impacted areas - Ongoing community engagement - Implementation of Ongoing Monitoring Plan to monitor the success or effectiveness of the treatment - Implementation of a mass flux study.

Cost / effectiveness / impact analysis

1	**Cost range estimate**	Category 3 Project actions > $450,000 < $2,000,000 For a smaller excavation (it is noted that additional investigation would likely be required to delineate the excavation extent).
2	**Effectiveness rating**	Low The option will likely be effective at reducing PFAS mass from the source area however is unknown to what extent it may contribute to reducing PFAS concentrations in Doughboy Hollow Creek.
3	**Implementation period / timeframe**	Primary implementation period Medium term: 1-3 years
4	**Potential impacts**	- Positive o Source area removed o No operation and maintenance costs following remedial works o Positive community message for management of a source area. - Negative o High cost to implement initially o Potential for works to have an impact on the Fire Station building o The benefits to meeting its objectives at the property are considered minor o Additional management may be required to store PFAS impacted soil on site (i.e. PFAS impacted stockpiles awaiting waste classification and disposal).
5	**Estimated net environmental benefit**	Marginal as this option will largely remove the source of PFAS, however surface water flows from this source area are intermittent and occur only in periods of rainfall. Furthermore, other non-SMA related sources may be contributing to PFAS impacts reported off-Base. Therefore, the overall reduction of PFAS concentrations and associated reductions in exposures to human health and impacts to the environment are likely to be minimal.

Risk-based analysis

6	**Proportion of action to risk**	The scale and cost of the action is considered disproportionate to the likelihood and scale of the risk.
7	**Best-practice status**	Treatment of the soil is one of a range of possible management actions for management of PFAS impacted soil. Other options, such as in-situ management (cap and contain), could be considered.
8	**Verification status**	Availability of licensed landfills to accept large quantities of PFAS impacted waste needs to be confirmed.
9	**Technology assessment**	Infrastructure and energy requirements - Plant and equipment required to undertake the excavation and haulage works - Following completion, no further energy is required - Monitoring required as a separate task. Reliability of technology - Treatment is feasible.

		Ability to monitor effectiveness - Monitoring can be completed. Ability to obtain any necessary approvals - On-Base works subject to ECC - No approval from NSW regulators required (on-Base works only). Availability of services and materials - Suitable import material needs to be sourced - Ability of landfills to accept PFAS impacted work needs to be confirmed.
10	**Risks and mitigation**	Secondary risks: - Delineation of appropriate excavation extents - Management of dust during excavation and transport - Volume increases. Residual risks: - PFAS impacted groundwater at the source is not addressed by this action.
11	**Key Dependencies**	Option is dependent on implementation of: - Data gap investigation at the former cantonment fire station - Mass flux study.

Defence implications

12	**Defence capability**	Low impact to Base operations.
13	**Project fit**	Not applicable.
14	**Scalability**	Generally, this option is scalable, however there may be constraints to the capacity of soil storage on-property or at the waste disposal facility.

Stakeholder impacts, views and consents

15	**Jurisdictional regulator/s**	External approvals required for off-Base disposal.
16	**Owner / occupier consents and views**	Lone Pine Barracks.
17	**Community**	Increased traffic/trucks during excavation works. No other community impacts identified in relation to this management option.

No #	**SS-2**
Title (functional)	Adsorption via stabilisation / immobilisation
Description	Ex-situ treatment of excavated soil, by techniques such as soil stabilisation and immobilisation using a commercially available product. Following treatment, the material could potentially be re-instated at the Base, placed in an on-Base containment cell or disposed off-Base to a licensed landfill. The soil volumes for potential treatment at the source area will require investigation and estimation.
Objective	Removal of PFAS contaminated soil from the Former Cantonment Fire Station and stabilisation or immobilisation with an amendment product to reduce leaching of PFAS to groundwater and surface water, and therefore reduce the mass of PFAS migrating from the source in groundwater and surface water.
How this objective contributes to managing the identified risk	By stabilising / immobilising the PFAS mass at the source area, migration of PFAS from the source area via surface water will be reduced. This may in turn reduce migration of PFAS off-Base to Doughboy Hollow Creek. By reducing PFAS concentrations migrating in surface water, this option may go some way to addressing: - R01 – Ingestion of home-grown red meat - R02 – Ingestion of home-grown milk - R03 – Cumulative ingestion of home-grown red meat, of home-grown milk and of eggs
The extent to which this option is expected to meet the objective	Expected to contribute to meeting the objective of reducing PFAS mass flux from the Former Cantonment Fire Station. The extent that this is able to be achieved will be related to volume and concentration of PFAS impacted soil that is removed and stabilised / immobilised. Excavation around the fire station building may present risk to the structural integrity of the building and this may prevent removal of all PFAS impacts (greater impacts have been identified close to the building footprint). Additionally, the treatment of PFAS in groundwater may be required in conjunction with soil treatment to assist with meeting the objectives. Operational, access and logistical constraints are anticipated, in particular where infrastructure /buildings are present. If immobilised soils are to remain on Base, they would require monitoring over time. Aligns with remediation / management hierarchy – i.e. remediation / management of source areas is preferred over pathways or receptors.

Whether the option addresses – source, – pathway – receptor, and/or – extended implementation period requirements	This option addresses the source and the pathway of PFAS contamination, by removing the PFAS impacted soil and immobilising it, thereby preventing it from leaching / migrating to groundwater and surface water.
Supplementary / complementary options	- Additional investigations to refine the source area for excavation will be required prior to works commencing. - P-2 - Surface Water Treatment - P-3 - Diversion of surface water from impacted areas - Ongoing community engagement - Implementation of Ongoing Monitoring Plan to monitor the success or effectiveness of the treatment - Implementation of a mass flux study.

Cost / effectiveness / impact analysis

1	**Cost range estimate**	Category 3 Project actions > $450,000 < $2,000,000
2	**Effectiveness rating**	Low The option will be effective at reducing PFAS migrating from the source area however is unknown to what extent it will contribute to reducing PFAS concentrations in Doughboy Hollow Creek.
3	**Implementation period / timeframe**	Primary implementation period – Medium term: 1-3 years
4	**Potential impacts**	- Positive o Source mass immobilised o Lower cost than excavation and off-Base disposal o Positive community message for management of a source area. - Negative o High cost to implement initially o Potential for the works to have an impact on the Fire Station building o The benefits to meeting its objectives at the property are considered minor o Ongoing monitoring of immobilised soils required into the future.
5	**Estimated net environmental benefit**	Marginal as this option will largely stabilise or immobilise the source of PFAS, however surface water flows from this source area are intermittent and occur only in periods of rainfall. Furthermore, other non-SMA related sources may be contributing to PFAS impacts reported off-Base. Therefore, the overall reduction of PFAS concentrations and associated reductions in exposures to human health and impacts to the environment are likely to be minimal.

Risk-based analysis

6	**Proportion of action to risk**	The scale and cost of the action is considered disproportionate to the likelihood and scale of the risk. Considered impacts: - Logistics over a short period of time 1 to 12 months Depending on volume to be treated - Truck movements - Dust management.
7	**Best-practice status**	Treatment of soil is one of a range of possible management actions for management of PFAS impacted soil presented in the NEMP. Other options, such as in-situ management (capping layer), could be considered. Additionally, the long-term stability of the treated soil matrix is not known.
8	**Verification status**	Treatment of soil, in particular the long-term effectiveness of stabilisation/solidification on soils at the Base are currently unknown.
9	**Technology assessment**	Infrastructure and energy requirements - Plant and equipment required to undertake the soil treatment works - Following completion, no further energy is required - Monitoring required as a separate task. Reliability of technology - Stabilisation / solidification trials at two other locations indicate the technology is feasible. Ability to monitor effectiveness - Leachate testing of treated material together with groundwater monitoring can be completed. Ability to obtain any necessary approvals - On-Base works subject to ECC - No approval from NSW regulators required, however it is expected that notification to and feedback from NSW agencies will be undertaken. Availability of services and materials - A range of appropriate contractors and treatment materials currently available.
10	**Risks and mitigation**	Secondary risks: - The immobilisation technology does not destroy or reduce contaminants, further management of solidified / stabilised material will be required (e.g. containment cell), if not placed back in the excavation. Residual risks: - Existing PFAS impacted groundwater not addressed by this action - PFAS will remain in soil at the Base. The long-term stability of the treated matrix is currently not known - PFAS in surface water from the Base is not substantially reduced as a result of this action given constraints associated with the fire station building and other source areas present at the SMA.

11	**Key Dependencies**	Option is dependent on the implementation of: - Data gap investigation at the former cantonment fire station - Mass flux study.

Defence implications

12	**Defence capability**	Low impact to Base operations.
13	**Project fit**	Not applicable.
14	**Scalability**	This option can be readily scaled up or down as required.

Stakeholder impacts, views and consents

15	**Jurisdictional regulator/s**	No external approvals required. However, notification to and feedback from NSW agencies is expected.
16	**Owner / occupier consents and views**	Lone Pine Barracks.
17	**Community**	No community impacts identified in relation to this management option.

No #	**SS-5**
Title (functional)	In-Situ Management (capping layer).
Description	Placement of a capping layer over soil profile to reduce leaching and migration of PFAS into surface water and groundwater.
Objective	Reduce leaching of PFAS into groundwater and surface water, and therefore reduce the mass flux of PFAS in groundwater and surface water.
How this objective contributes to managing the identified risk	By isolating the PFAS mass at the source area from interaction with infiltrating water, the migration of PFAS from the source area via surface water will be reduced. This may in turn reduce PFAS concentrations in Doughboy Hollow Creek (down gradient). By reducing PFAS concentrations migrating in surface water, this option may go some way to addressing: - R01 – Ingestion of home-grown red meat - R02 – Ingestion of home-grown milk - R03 – Cumulative ingestion of home-grown red meat, of home-grown milk and of eggs
The extent to which this option is expected to meet the objective	Reduction in PFAS discharges to surface water may reduce PFAS concentrations in Doughboy Hollow Creek. This option may reduce migration of PFAS off-Base to Doughboy Hollow Creek. Capping is likely to reduce infiltration through soils at the source, which leach to groundwater.
Whether the option addresses – source, – pathway – receptor, and/or – extended implementation period requirements	Physical capping layers have been proven to remove the direct contact pathway for exposure to a contaminant source and the surface water runoff pathway. The PFAS will remain in situ, which does not remove the migration pathway of leaching to groundwater, however it is likely to reduce PFAS impacts in this pathway as infiltration of water through the soils at the source will be reduced.
Supplementary / complementary options	- Additional investigations to refine the area for capping will be required prior to works commencing. - P-2 - Surface Water Treatment - P-3 - Diversion of surface water from impacted areas - Ongoing community engagement - Implementation of Ongoing Monitoring Plan to monitor the success or effectiveness of the treatment - Implementation of a mass flux study.

Cost / effectiveness / impact analysis

1	**Cost range estimate**	Category 3 Project actions > $450,000 < $2,000,000 (the above provides a preliminary cost estimate per source)
2	**Effectiveness rating**	Low The option will likely be effective at reducing PFAS migrating from the source area, however is unknown to what extent it will contribute to reducing PFAS concentrations in Doughboy Hollow Creek.
3	**Implementation period / timeframe**	Primary implementation period – Short term: 1-12 months from the date of the PMAP for a small capping layer.

4	**Potential impacts**	- Positive
		  o Source mass isolated from interaction with infiltrating water
		  o Lower cost than excavation and off-Base disposal and stabilisation / immobilisation
		  o Positive community message for management of a source area.
		- Negative
		  o Potential for the works to have an impact on the Fire Station building
		  o The benefits to meeting its objectives at the property are considered marginal
		  o PFAS source mass will remain in place
		  o Ongoing monitoring of the integrity of the cap is required into the future.

5	**Estimated net environmental benefit**	Marginal, as this option will largely isolate the source of PFAS from infiltrating water. Surface water flows from this source area are intermittent and occur only in periods of rainfall. Furthermore, other non-SMA related sources may be contributing to PFAS impacts reported off-Base. Therefore, the overall reduction of PFAS concentrations and associated reductions in exposures to human health and impacts to the environment are likely to be minimal. The cost of implementing a capping layer over the soil with the greatest PFAS impacts (close to the fire station building) is likely to be relatively low (in comparison to other options) and may be worth consideration even if the associated reductions in exposures to human health and impacts to the environment are likely to be minimal.

Risk-based analysis

6	**Proportion of action to risk**	The scale and cost of the action is considered marginally proportional to the likelihood and scale of the risk, if the cost of this option is at the low end of the cost range estimate. Considered impacts: - Logistics over a short period of time 1 to 12 months - Truck movements - Dust management.
7	**Best-practice status**	With reference to the management options currently available in the NEMP (HEPA, 2020), this option would be considered best practice.
8	**Verification status**	This option has been successfully used to manage PFAS contaminated soils at other sites in Australia.
9	**Technology assessment**	Infrastructure and energy requirements - Plant and equipment required to undertake the capping works - Following completion, no further energy is required - Monitoring required as a separate task. Reliability of technology - Capping is a relatively mature technology with a range of available options.

		Ability to monitor effectiveness - surface water and groundwater monitoring can be used to monitor the effectiveness of this option. Ability to obtain any necessary approvals - On-Base works subject to ECC - No approval from NSW regulators required, however depending on capping design, if any soil required disposal off-Base, it is expected that notification to and feedback from NSW agencies will be undertaken. Availability of services and materials - Capping is readily available and can be supplied by both remediation and civil contractors with experience on remediation projects in Australia.
10	**Risks and mitigation**	Secondary risks: - Soil with low level PFAS impacts outside of the capped area may continue to leach PFAS to surface water which migrates to Doughboy Hollow Creek. Residual risks: PFAS will remain in soil at the Base. The integrity of the cap will require ongoing monitoring.
11	**Key Dependencies**	This option is dependent on implementation of: - Data gap investigation at the former cantonment fire station - Mass flux study.

Defence implications

12	**Defence capability**	Low impact to Base operations for capping – assuming either a very shallow excavation, or no excavation is required to implement the cap.
13	**Project fit**	Not applicable.
14	**Scalability**	This option can be readily scaled up or down as required.

Stakeholder impacts, views and consents

15	**Jurisdictional regulator/s**	No external approvals required. However, notification to and feedback from NSW agencies is expected.
16	**Owner / occupier consents and views**	Lone Pine Barracks.
17	**Community**	No community impacts identified in relation to this management option.

No #	**SS-6**
Title (functional)	On-site containment in an engineered facility. Excavate soil (with or without treatment) for storage in on-Base containment cell.
Description	Removal of PFAS impacted soils from the Former Cantonment Fire Station for storage in an appropriately designed containment cell located on-Base. The excavation will be backfilled with clean soil. The soil can be treated (SS-2) or stabilised before placement in cell for medium to long-term storage. This would further reduce leaching potential from cell and could enable construction of a cell of less complexity.
Objective	Removal of PFAS contaminated soil from key source areas to reduce leaching of PFAS into groundwater and surface water, and therefore reduce the mass flux of PFAS in groundwater and surface water. Design of cell to prevent leaching of PFAS and secondary impacts to groundwater.
How this objective contributes to managing the identified risk	By removing the PFAS mass at the source area and containing it in a cell where it can no longer interact with water, the migration of PFAS from the source area via surface water will be reduced. This may in turn reduce migration of PFAS off-Base to Doughboy Hollow Creek. (down gradient). By reducing PFAS concentrations migrating in surface water, this option may go some way to addressing: - R01 – Ingestion of home-grown red meat - R02 – Ingestion of home-grown milk - R03 – Cumulative ingestion of home-grown red meat, of home-grown milk and of eggs
The extent to which this option is expected to meet the objective	Expected to contribute to meeting the objective of reducing PFAS mass flux from the source areas. The extent that this is able to be achieved will be related to volume of PFAS impacted soil that is removed. Operational, access and logistical constraints are anticipated. Aligns with remediation / management hierarchy – i.e. remediation / management of source areas is preferred over management of pathways or receptors.
Whether the option addresses – source, – pathway – receptor, and/or – extended implementation period requirements	This option addresses the source and the pathway of PFAS contamination, by removing PFAS mass in the soil and thereby preventing it from leaching / migrating to groundwater and surface water.
Supplementary / complementary options	- SS-2 - Adsorption via Stabilisation / Immobilisation - P-2 - Surface Water Treatment - P-3 - Diversion of surface water from impacted areas - Additional investigations to refine the area for excavation to the engineered facility - Ongoing community engagement - Implementation of OMP to monitor the success or effectiveness of the treatment - Implementation of a mass flux study.

Cost / effectiveness / impact analysis

1	**Cost range estimate**	Category 2 Medium works notification to PWC required above $2 million $1,500,000 < $15,000,000
2	**Effectiveness rating**	Low The option will remove the PFAS source. However, it is unknown to what extent it will contribute to reducing PFAS concentrations in Doughboy Hollow Creek.
3	**Implementation period / timeframe**	Primary implementation period Short term: 1-12 months for a simple containment cell design and small excavation
4	**Potential impacts**	- Positive o Source mass removed o No ongoing maintenance costs for the remediation site, though the containment cell, may require maintenance and monitoring of leachate etc o Positive community message for management of a source area. - Negative o Potential for excavation works to have an impact on the Fire Station building o The benefits to meeting its objectives at the property are considered marginal o Containment cell will take up space on the Base that could otherwise be used to meet capability requirements o PFAS source mass will remain in place. Ongoing monitoring of the integrity of the cap is required into the future.
5	**Estimated net environmental benefit**	Marginal, as this option will remove the source of PFAS, however, surface water flows from this source area are intermittent and occur only in periods of rainfall. Furthermore, other non-SMA related sources may be contributing to PFAS impacts reported off-Base. Therefore, the overall reduction of PFAS concentrations and associated reductions in exposures to human health and impacts to the environment are likely to be minimal.

Risk-based analysis

6	**Proportion of action to risk**	The scale and cost of the action is considered disproportionate to the likelihood and scale of the risk. Considered impacts: - Logistics over a short period of time 1 to 12 months. Depending on volume to be excavated - Loss of space in cell area - Site selection board process for site selection - Truck movements - Reinstate excavation with clean soil.

7	**Best-practice status**	With reference to the management options currently available in the NEMP (HEPA, 2020), this option would be considered best practice.
8	**Verification status**	This management option has been used to successfully treat/manage PFAS contaminated soil at other sites in Australia.
9	**Technology assessment**	Infrastructure and energy requirements - Plant and equipment required to undertake the excavation and containment works - Following completion, further effort is required (I.e. ongoing treatment of leachate etc) - Monitoring of the containment cell is required as a separate task. Reliability of technology - Containment cells are a mature technology with a range of available options. Ability to monitor effectiveness - Surface water and groundwater can be monitored to assess the effectiveness of this option. Ability to obtain any necessary approvals - On-Base works subject to ECC - Site selection board approval for location of the containment cell - No approval from NSW regulators required, however depending on cell design, if any soil required disposal off-Base, it is expected that notification to and feedback from NSW agencies will be undertaken. Availability of services and materials - Containment cells can be supplied by both remediation and civil contractors with experience on remediation projects in Australia.
10	**Risks and mitigation**	Secondary risks: - Soil with low level PFAS impacts outside of the excavation area may continue to leach PFAS to surface water which migrates to Doughboy Hollow Creek. Residual risks: - PFAS will remain in soil at the Base. The integrity of the containment cell will require ongoing monitoring.
11	**Key Dependencies**	Option is dependent upon the implementation of: - Data gap investigation at the former cantonment fire station - Mass flux study - An appropriate space for the engineered facility on-Site, which is subject to Site selection Board approval.

Defence implications

12	**Defence capability**	Moderate impact to base operations, considering land which could otherwise be used for operational purposes will be taken up by the containment cell.
13	**Project fit**	Not Applicable.

14	**Scalability**	This option can be readily scaled up or down as required. The limitation will be the size of the containment cell that may be permissible at the Base for the storage of large volumes of soil.

Stakeholder impacts, views and consents

15	**Jurisdictional regulator/s**	No external approvals required. However, notification to and feedback from NSW agencies is expected.
16	**Owner / occupier consents and views**	Lone Pine Barracks.
17	**Community**	No community impacts identified in relation to this management option.

E2.2 Pathway Management (whole of Base)

No #	**P-2**
Title (functional)	Surface Water Treatment
Description	Collection and treatment of PFAS impacted surface water from drains. The following areas have been considered: - Northern discharge point from the Base towards Doughboy Hollow Creek.
Objective	Prevent PFAS impacted surface water in drains from migrating to groundwater or to off-Base areas. Surface water has been identified as the key pathway contributing to off-Base human health risks.
How this objective contributes to managing the identified risk	A reduction in the mass load of PFAS in surface water leaving the Base may reduce PFAS concentrations in Doughboy Hollow Creek. The option may go some way to addressing the following risks: - R01 – Ingestion of home-grown red meat - R02 – Ingestion of home-grown milk - R03 – Cumulative ingestion of home-grown red meat, of home-grown milk and of eggs
The extent to which this option is expected to meet the objective	The technology has been implemented at RAAF Base Williamtown. Expected to partly meet the objective of reducing PFAS mass load in surface water. However, an appropriate system would need to be designed to capture run-off during rain fall events. The extent that this is able to be achieved may be influenced by the volume of water captured during rainfall events. Surface water treatment is unlikely to capture and treat the entire volume of water discharged from the Site during high flow events. Aligns with remediation / management hierarchy – i.e. remediation / management of areas with elevated PFAS concentrations. Passive treatment has been ruled out due to the risk of flooding.
Whether the option addresses – source, – pathway – receptor, and/or – extended implementation period requirements	This option addresses the contamination migration pathway.
Supplementary / complementary options	- SS-1 Excavation and Off-Base Disposal - SS-2 Adsorption via Stabilisation / Immobilisation - SS-5 In-Situ Management (cap/contain) - SS-6 - On-site containment in an engineered facility - A-1 - Ongoing community engagement to reduce or prevent PFAS exposure - Implementation of OMP to monitor the success or effectiveness of the treatment - Implementation of a mass flux study.

Cost / effectiveness / impact analysis

1	**Cost range estimate**	Category 2 Medium works notification to PWC required above $2 million $1,500,000 < $15,000,000
2	**Effectiveness rating**	Low – Surface water concentrations are less than the PFAS NEMP (2020) recreational water criteria at this location. The option will remove PFAS mass from the pathway. However, it is unknown to what extent it will contribute to reducing PFAS concentrations overall in Doughboy Hollow Creek.
3	**Implementation period / timeframe**	Primary implementation period – Medium term: 1-3 years on Base Construction / commissioning / commencement of operations. – Long term: beyond 3 years Operational phase
4	**Potential impacts**	- Positive o PFAS mass removed from the environment o Positive community message for management of a source area. - Negative o Ongoing costs o Management of PFAS waste stream o The benefits to meeting its objectives at the property are considered marginal o Ongoing monitoring is required o PFAS impacted groundwater soil not addressed by this action o Surface water treatment is unlikely to capture and treat the entire volume of water discharged from the Site during high flow events.
5	**Estimated net environmental benefit**	Low -considering the relatively low PFAS concentrations in the surface water and the energy required and waste generated to remove the PFAS from water.

Risk-based analysis

6	**Proportion of action to risk**	The scale and cost of the action is considered disproportionate to the likelihood and scale of the risk. Considered impacts: - Logistics over commissioning period - Loss of land to detention basins - Site selection board process for site selection - Truck movements - Energy requirements - Waste generation - Ongoing cost.

7	**Best-practice status**	Treatment of surface water is one of a range of possible management actions for management of PFAS impacted surface water. Other options, such as drain diversions (option P-3), could be considered.
8	**Verification status**	Verified by operation of water treatment plants on other Defence Bases.
9	**Technology assessment**	Infrastructure and energy requirements - Treatment plant and equipment required to be provided by a contractor - Following completion of treatment, no further energy is required. - Monitoring required as a separate task. Reliability of technology - Technology has been used successfully at other Bases for removal of PFAS from the environment. Ability to monitor effectiveness - Ongoing monitoring will be implemented to measure success / effectiveness of the technology - Ongoing monitoring of surface water as part of the OMP. Ability to obtain any necessary approvals - No approval from regulators required for treatment on the Base. Notification to and feedback from NSW agencies is expected to be undertaken. Availability of services and materials - Numerous contractors and treatment options available.
10	**Risks and mitigation**	Secondary risks: - Off-Base sources continue to discharge PFAS and no improvement is demonstrated. Residual risks: - Ongoing management of waste streams - PFAS at the source is not addressed, treatment is required indefinitely
11	**Key Dependencies**	SS-1 Excavation and Off-Base Disposal SS-2 Adsorption via Stabilisation / Immobilisation SS-5 In-Situ Management (cap/contain) SS-6 On-site containment in an engineered facility Implementation of a mass flux study Implementation of OMP.

Defence implications

12	**Defence capability**	Moderate impact to Base operations and capability, considering land which could otherwise be used for operational purposes will be taken up by the water treatment plant.
13	**Project fit**	The technology is currently used at other Bases.
14	**Scalability**	This option can be readily scaled up or down as required. The treatment can be completed on a number of areas, depending on accessibility.

Stakeholder impacts, views and consents

15	**Jurisdictional regulator/s**	On-Base: Site Selection Board approval may be required. Off-Base: NSW EPA (notification may be required for disposal of generated wastes).
16	**Owner / occupier consents and views**	On-Base: Lone Pine Barracks.
17	**Community**	No community impacts identified in relation to this management option. The treatment of surface water will be viewed as a positive outcome, by the community.

No #	P-2
Title (functional)	Surface Water Treatment
Description	Collection and treatment of PFAS impacted surface water from drains. The following areas have been considered: - Southern discharge point from the Base towards Doughboy Hollow Creek
Objective	Prevent PFAS impacted surface water in drains from migrating to groundwater or to off-Base areas. Surface water has been identified as the key pathway contributing to off-Base human health risks.
How this objective contributes to managing the identified risk	A reduction in the mass load of PFAS in surface water leaving the Base may reduce PFAS concentrations in Doughboy Hollow Creek. The option may go some way to addressing the following risks: - R01 – Ingestion of home-grown red meat - R02 – Ingestion of home-grown milk - R03 – Cumulative ingestion of home-grown red meat, of home-grown milk and of eggs
The extent to which this option is expected to meet the objective	The technology has been implemented at RAAF Base Williamtown. Expected to partly meet the objective of reducing PFAS mass load in surface water. However, an appropriate system would need to be designed to capture run-off during rain fall events. The extent that this is able to be achieved may be influenced by the volume of water captured during rainfall events. Surface water treatment is unlikely to capture and treat the entire volume of water discharged from the Site during high flow events. Aligns with remediation / management hierarchy – i.e. remediation / management of areas with elevated PFAS concentrations. Passive treatment has been ruled out due to the risk of flooding.
Whether the option addresses – source, – pathway – receptor, and/or – extended implementation period requirements	This option addresses the contamination migration pathway.
Supplementary / complementary options	- SS-1 Excavation and Off-Base Disposal - SS-2 Adsorption via Stabilisation / Immobilisation - SS-5 In-Situ Management (cap/contain) - SS-6 - On-site containment in an engineered facility - A-1 - Ongoing community engagement to reduce or prevent PFAS exposure - Implementation of Ongoing Monitoring Plan to monitor the success or effectiveness of the treatment - Implementation of a mass flux study.

Cost / effectiveness / impact analysis

1	**Cost range estimate**	Category 2 Medium works notification to PWC required above $2 million $1,500,000 < $15,000,000
2	**Effectiveness rating**	Low – Surface water concentrations are less than the PFAS NEMP recreational water criteria at this location. The option will remove PFAS mass from the pathway. However, it is unknown to what extent it will contribute to reducing PFAS concentrations overall in Doughboy Hollow Creek.
3	**Implementation period / timeframe**	Primary implementation period – Medium term: 1-3 years on Base Construction / commissioning / commencement of operations. – Long term : beyond 3 years Operational phase
4	**Potential impacts**	- Positive o PFAS mass removed from the environment o Positive community message for management of a source area. - Negative o Ongoing costs o Management of PFAS waste stream o The benefits to meeting its objectives at the property are considered marginal o Ongoing monitoring is required o PFAS impacted groundwater soil not addressed by this action o Surface water treatment is unlikely to capture and treat the entire volume of water discharged from the Site during high flow events.
5	**Estimated net environmental benefit**	Low -considering the relatively low PFAS concentrations in the surface water and the energy required and waste generated to remove the PFAS from water.

Risk-based analysis

6	**Proportion of action to risk**	The scale and cost of the action is considered disproportionate to the likelihood and scale of the risk. Considered impacts: - Logistics over commissioning period - Loss of land to detention basins - Site selection board process for site selection - Truck movements - Energy requirements - Waste generation - Ongoing cost.

7	**Best-practice status**	Treatment of surface water is one of a range of possible management actions for management of PFAS impacted surface water. Other options, such as drain diversions (option P-3), could be considered. .
8	**Verification status**	Verified by operation of water treatment plants on other Defence Bases.
9	**Technology assessment**	Infrastructure and energy requirements - Treatment plant and equipment required to be provided by a contractor - Following completion of treatment, no further energy is required. - Monitoring required as a separate task. Reliability of technology - Technology has been used successfully at other Bases for removal of PFAS from the environment. Ability to monitor effectiveness - Ongoing monitoring will be implemented to measure success / effectiveness of the technology - Ongoing monitoring of surface water as part of the OMP. Ability to obtain any necessary approvals - No approval from regulators required for treatment on the Base Notification to and feedback from NSW agencies is expected to be undertaken. Availability of services and materials - Numerous contractors and treatment options available.
10	**Risks and mitigation**	Secondary risks: - Off-Base sources continue to discharge PFAS and no improvement is demonstrated. Residual risks: - Ongoing management of waste streams - PFAS at the source is not addressed, treatment is required indefinitely
11	**Key Dependencies**	SS-1 Excavation and Off-Base Disposal SS-2 Adsorption via Stabilisation / Immobilisation SS-5 In-Situ Management (cap/contain) SS-6 On-site containment in an engineered facility Implementation of a mass flux study.

Defence implications

12	**Defence capability**	Moderate impact to Base operations and capability, considering land which could otherwise be used for operational purposes will be taken up by the water treatment plant.
13	**Project fit**	The technology is currently used at other Bases.
14	**Scalability**	This option can be readily scaled up or down as required. The treatment can be completed on a number of areas, depending on accessibility.

Stakeholder impacts, views and consents

15	**Jurisdictional regulator/s**	On-Base: Site Selection Board approval may be required. Off-Base: NSW EPA (notification may be required for disposal of generated wastes).
16	**Owner / occupier consents and views**	On-Base: Lone Pine Barracks.
17	**Community**	No community impacts identified in relation to this management option. The treatment of surface water will be viewed as a positive outcome, by the community.

No #	**P-2**
Title (functional)	Surface / Waste Water Treatment
Description	Collection and treatment of PFAS impacted surface / waste water from the sewage line which discharges to the Singleton STP.
Objective	Prevent PFAS impacted sewage from migrating to off-Base areas. Whilst surface water has been identified as the key pathway contributing to off-Base human health risks, there is presently insufficient data to establish that waste water sourced from the Base and discharged to the STP is a significant pathway.
How this objective contributes to managing the identified risk	A reduction in the mass load of PFAS in surface water leaving the Base will reduce the potential for human or ecological receptors to be exposed to elevated concentrations of PFAS. The option may go some way to addressing the following risks: - R01 – Ingestion of home-grown red meat - R02 – Ingestion of home-grown milk - R03 – Cumulative ingestion of home-grown red meat, of home-grown milk and of eggs
The extent to which this option is expected to meet the objective	The technology has been implemented at RAAF Base Williamtown. Expected to partly meet the objective of reducing PFAS mass load in surface and waste water. However, an appropriate system would need to be designed to treat raw sewage flows before entering the Singleton STP. The extent that this is able to be achieved may be influenced by the volume of water treated. Aligns with remediation / management hierarchy – i.e. remediation / management of areas with elevated PFAS concentrations.
Whether the option addresses – source, – pathway – receptor, and/or – extended implementation period requirements	This option addresses the contamination migration pathway.
Supplementary / complementary options	- Implementation of OMP to monitor the success or effectiveness of the treatment - Implementation of a mass flux study.

Cost / effectiveness / impact analysis

1	**Cost range estimate**	Category 2 Medium works notification to PWC required above $2 million $1,500,000 < $15,000,000
2	**Effectiveness rating**	Low – Surface water concentrations are less than the PFAS NEMP (2020) drinking water criteria at the location sampled during the DSI (2019b). The option will remove PFAS mass from the pathway (provided a suitable treatment train for raw sewage can be developed). However, it is unknown to what extent it will contribute to reducing PFAS concentrations overall at the Singleton STP.

3	**Implementation period / timeframe**	Primary implementation period – Medium term: 1-3 years on Base Construction / commissioning / commencement of operations. – Long term : beyond 3 years Operational phase
4	**Potential impacts**	Environmental: - Truck movements associated with construction Socio-economic: - Removal of PFAS from environment will result in an improvement of land and water quality - Improve community confidence in using the land and water - Strengthen Defence and community relationships - Positive community message for management of a source area - High cost and energy expenditure for low PFAS concentrations.
5	**Estimated net environmental benefit**	Low considering the low PFAS concentrations in the water, the energy required and waste generated to remove the PFAS from water.

Risk-based analysis

6	**Proportion of action to risk**	The scale and cost of the action is considered disproportionate to the likelihood and scale of the risk. PFAS concentrations in the raw sewage had a maximum concentration of 0.04 µg/L. Would require pre-treatment to remove organic pollutants before PFAS could be removed. Considered impacts: - Logistics over commissioning period - Loss of land for treatment plant - Site selection board process for site selection - Truck movements - Energy requirements - Waste generation - Ongoing cost.
7	**Best-practice status**	Water treatment is likely the only possible management action for management of PFAS impacted sewage. Considering that the sewage line already discharges to the external sewer network.
8	**Verification status**	Verified by operation of water treatment plants on other Defence Bases.
9	**Technology assessment**	Infrastructure and energy requirements - Treatment plant and equipment required to be provided by a contractor - Pilot trial will be required due to raw effluent - Following completion of treatment, no further energy is required. - Monitoring required as a separate task. Reliability of technology - Technology has been used successfully at other Bases for removal of PFAS from the environment. Ability to monitor effectiveness - Ongoing monitoring will be implemented to measure success / effectiveness of the technology.

		- Ongoing monitoring of surface water as part of the OMP. Ability to obtain any necessary approvals - No approval from regulators required for treatment on the Base. Notification to and feedback from NSW agencies is expected to be undertaken. Availability of services and materials - Numerous contractors and treatment options available.
10	**Risks and mitigation**	Secondary risks: - Off-Base sources continue to discharge PFAS and no improvement is demonstrated. Residual risks: - Ongoing management of waste streams - PFAS at the source is not addressed, treatment is required indefinitely.
11	**Key Dependencies**	Implementation of an OMP. Implementation of a mass flux study.

Defence implications

12	**Defence capability**	Moderate impact to Base operations and capability, considering land which could otherwise be used for operational purposes will be taken up by the water treatment plant.
13	**Project fit**	The technology is currently used at other Bases.
14	**Scalability**	This option can be readily scaled up or down as required. The treatment can be completed on a number of areas, depending on accessibility.

Stakeholder impacts, views and consents

15	**Jurisdictional regulator/s**	On-Base: Site Selection Board approval may be required. Off-Base: NSW EPA (notification may be required for disposal of generated wastes).
16	**Owner / occupier consents and views**	On-Base: Lone Pine Barracks.
17	**Community**	No community impacts identified in relation to this management option. The treatment of surface water will be viewed as a positive outcome, by the community.

E2.3 Receptor Management (whole of Management Area)

No #	A-1
Title (functional)	Administrative control through engagement and reinforcement of HHRA.
Description	Provide up to date information relating to PFAS advice via factsheets and community announcements (Noting that Defence has no authority in off-Base areas to provide dietary advice etc. that falls under the responsibility of the NSW EPA). This action is an existing commitment of the OMP and therefore forms part of the recommendation to implement the OMP (refer to Section 7).
Objective	Prevent the community from potentially being exposed to elevated concentrations of PFAS via ongoing community engagement.
How this objective contributes to managing the identified risk	Reduce the potential for the community to be exposed to PFAS via large quantities of PFAS impacted home grown meat, milk and the cumulative ingestion of home-grown red meat, home-grown milk and of eggs. The risk the selected option addresses: - R01 – Ingestion of home-grown red meat - R02 – Ingestion of home-grown milk - R03 – Cumulative ingestion of home-grown red meat, of home-grown milk and of eggs
The extent to which this option is expected to meet the objective	There has been engagement with the community since 2017. The recent environmental investigation findings have been presented to the community to date. Ongoing community engagement will be required.
Whether the option addresses – source, – pathway – receptor, and/or – extended implementation period requirements	This option addresses the receptor of the contamination.
Supplementary / complementary options	- SS-1 Excavation and Off-Base Disposal - SS-2 Adsorption via Stabilisation / Immobilisation - SS-5 In-Situ Management (cap/contain) - SS-6 - On-site containment in an engineered facility - P-2 Surface Water Treatment - P-3 Collection of surface water from drains for treatment.

Cost / effectiveness / impact analysis

1	**Cost range estimate**	Category 4	Community level actions	<$500,000
2	**Effectiveness rating**	Medium The option, is projected to make significant progress towards meeting its objectives, provided people can easily implement the changes to their dietary habits.		

3	**Implementation period / timeframe**	Primary implementation period - Currently: ongoing engagement, implemented throughout the investigation phases at the SMA - Long term: to continue following implementation of PMAP and ongoing monitoring plan.
4	**Potential impacts**	Environmental: - PFAS impact remains in soil / groundwater if no other actions implemented - Ongoing engagement required during PMAP implementation and ongoing monitoring. Socio-economic: - Continue to improve community awareness of precautionary advice on recreation users of water ways in Management Area - Strengthen Defence and community relationships.
5	**Estimated net environmental benefit**	No net benefit to environment.

Risk-based analysis

6	**Proportion of action to risk**	Ongoing community engagement and reinforcement of HHRA (AECOM, 2021b) results will be required to minimise exposure to PFAS through home grown produce, livestock consumption and livestock milk consumption. This management action is anticipated to have no impact on logistics on Base, largely related to community engagement.
7	**Best-practice status**	Ongoing community engagement is considered 'best-practice' as it involves up-to date information to the community on precautionary advice. Although this action does not involve destruction of PFAS, it does reduce exposure to PFAS for people grow and consume their own produce.
8	**Verification status**	Community engagement has been successfully implemented at other Sites. Success at the SMA will depend on ongoing engagement to ensure the community is informed of new findings or changes to precautionary advice.
9	**Technology assessment**	Administrative control requires ongoing management and engagement.
10	**Risks and mitigation**	- Ongoing community engagement. Residual risks: - PFAS impacted surface water or groundwater not addressed by this action.
11	**Key Dependencies**	Option is not dependent upon implementation of other options or external factors.

Defence implications

12	**Defence capability**	Low impact to Base operations.
13	**Project fit**	The community engagement process has been implemented at the Base and other Defence Bases / Sites.
14	**Scalability**	This option can be readily scaled up or down as required.

Stakeholder impacts, views and consents

15	**Jurisdictional regulator/s**	No external approvals required. However, updates to precautionary advice from NSW agencies and / or federal government will need to be communicated to the community.
16	**Owner / occupier consents and views**	No consents are required to implement this option. No stakeholder views on this option identified.
17	**Community**	The community within the Management Area has been informed of the results of the investigation and risk assessment works within the Management Area via factsheets, environmental reports and Community Walk-In Sessions. Ongoing community engagement will be required.

APPENDIX F Additional figures

List of figures

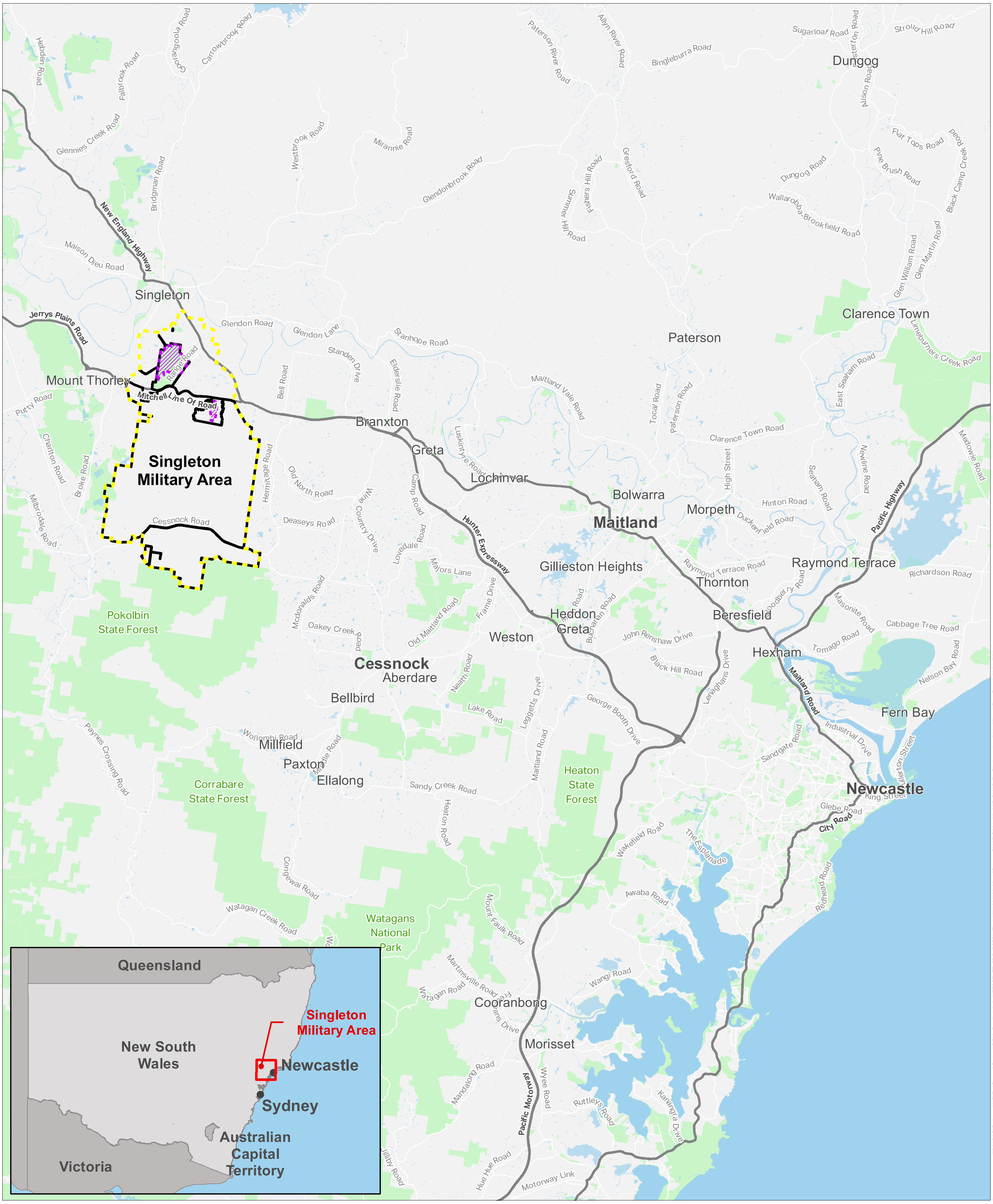


FIGURE 1: SITE LOCATION

km
0 5 10

Legend

- Property boundary
- Former Investigation Area
- On-Site Management Area
- Highways
- Main Roads
- Waterbody
- Parks, Forests and Reserves

Source: © Department Finance, Services & Innovation (2018)

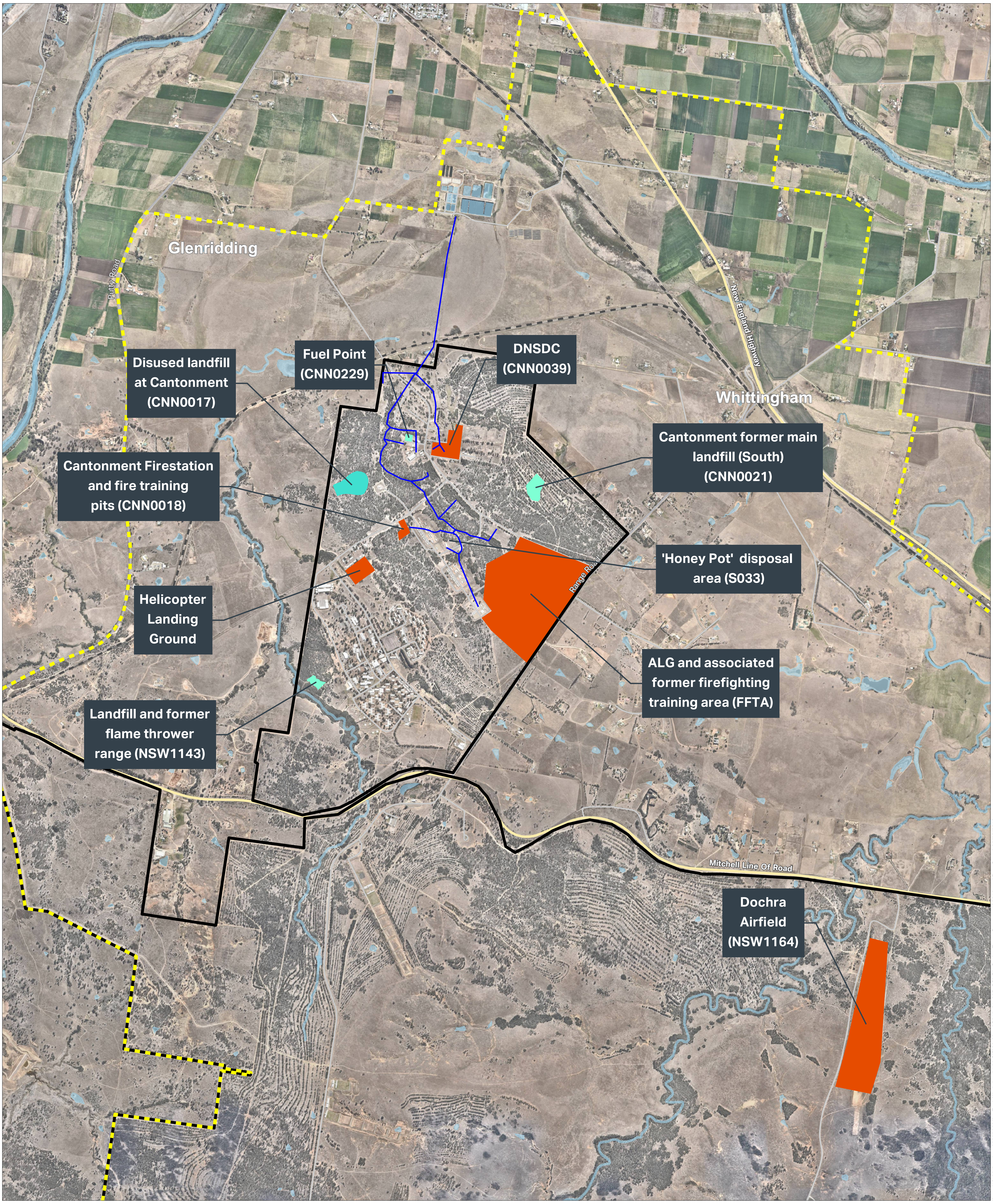


FIGURE 2: PMAP Source Areas

N

km
0 0.5 1

- Highways
- Main Roads
- Local Roads
- Railway
- Watercourses
- Waterbody
- State Forest
- Sewer
- PMAP Source
- DSI Source Area
- Investigation Area
- Property Boundary

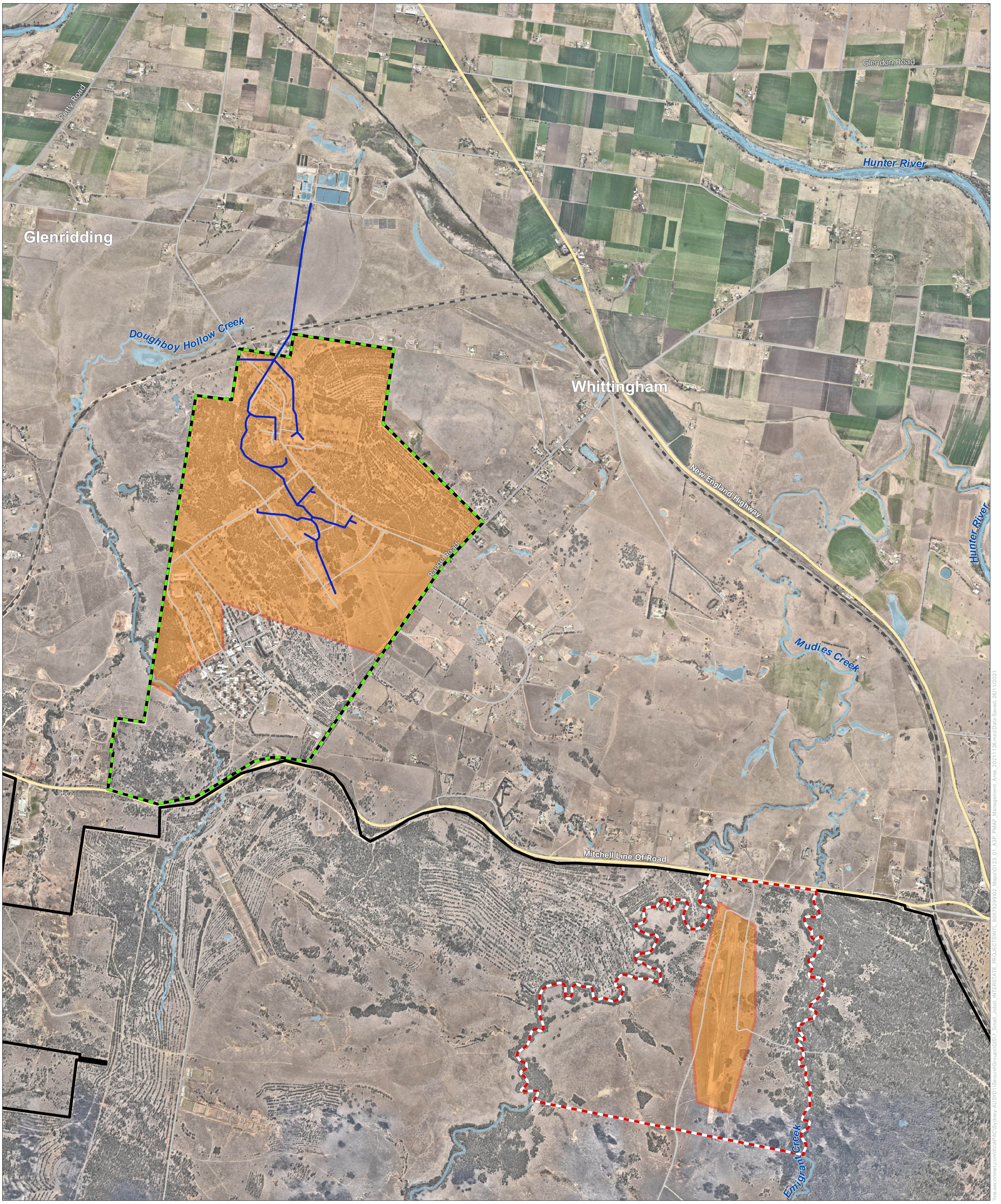


FIGURE 3: MANAGEMENT AREA

AECOM

- Highways
- Main Roads
- Local Roads
- Railway
- Watercourses
- Sewer
- Waterbody
- Property Boundary
- Dochra Airfield Investigation Boundary
- Cantonment Boundary
- On-Site Management Area

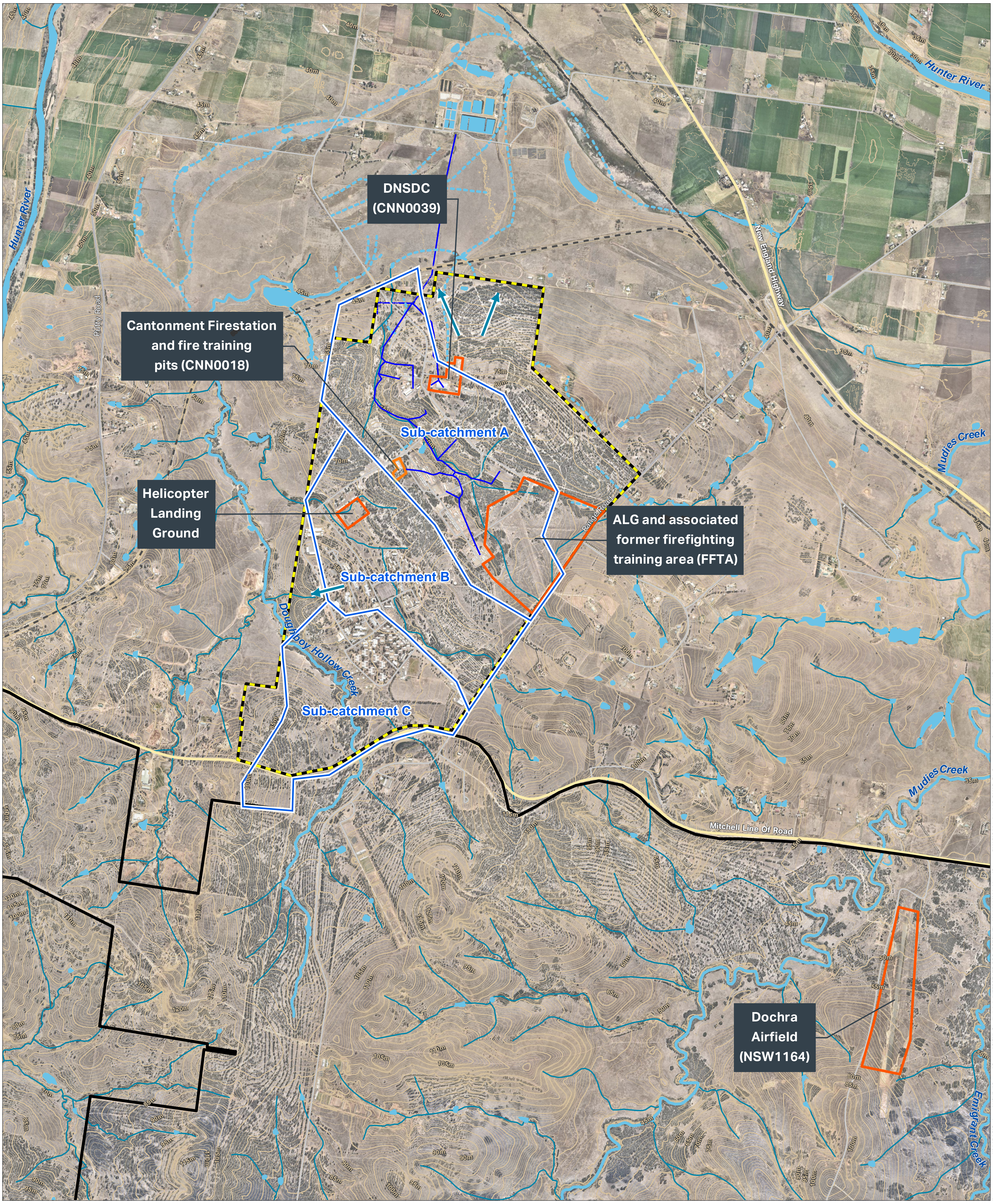


FIGURE 4: CANTONMENT CATCHMENTS

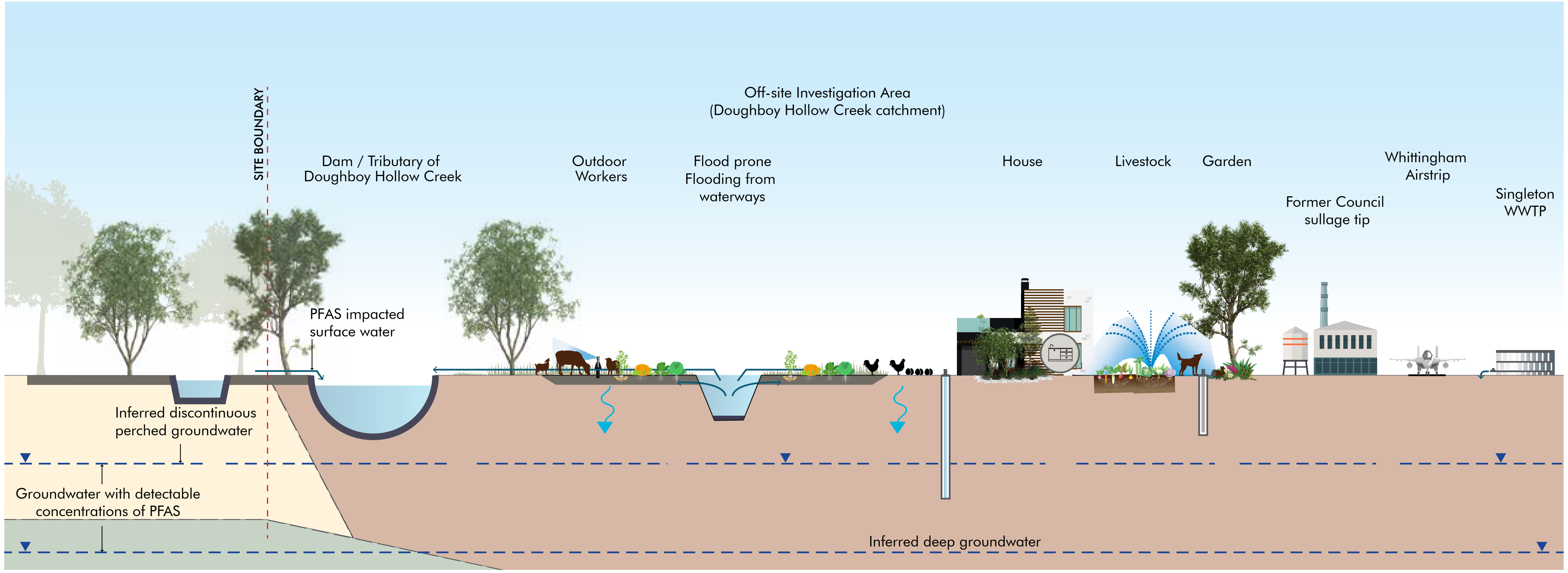
AECOM

0 0.45 0.9 km

Source: © Department Finance, Services & Innovation (2018)

- Cantonment Boundary
- Property Boundary
- CSR boundaries
- State Forest
- Contours (1m)
- Overland flow
- Waterbody
- Drainage line
- Watercourses
- Undefined Drainage Lines
- Catchment Boundaries
- Sewer
- Railway
- Highways
- Main Roads
- Local Roads

AECOM



Not to scale

Migration Pathways

Discharge or spilling of AFFF at the ground surface, sorption of PFAS to soil
Wind dispersion of PFAS impacted fine grained surface soil and dust if disturbed
Floodwaters disperse PFAS to soil
Surface water and sediment migration along drainage lines to catchment areas (via overland flow)

Sorption of PFAS in surface water to sediment and re-solubilisation to surface water
Residential bores pumping impacted groundwater
PFAS in groundwater and surface water used for irrigation and livestock water supply
Discharge of effluent from sewage treatment plant to waterways
Uptake of PFAS into biota

Source	PFAS in groundwater	PFAS in surface water	PFAS in surface soil	PFAS in sediment	PFAS in biota
Human Receptor	Residents	Residential Outdoor workers Recreational users	Residential Outdoor workers	Recreational users	Residents
Exposure Pathways	Incidental ingestion and dermal uptake	Incidental ingestion and dermal uptake	Incidental ingestion, inhalation and dermal uptake	Ingestion and dermal uptake	Ingestion

Key

Groundwater
Surface water runoff
Infiltration / recharge of groundwater

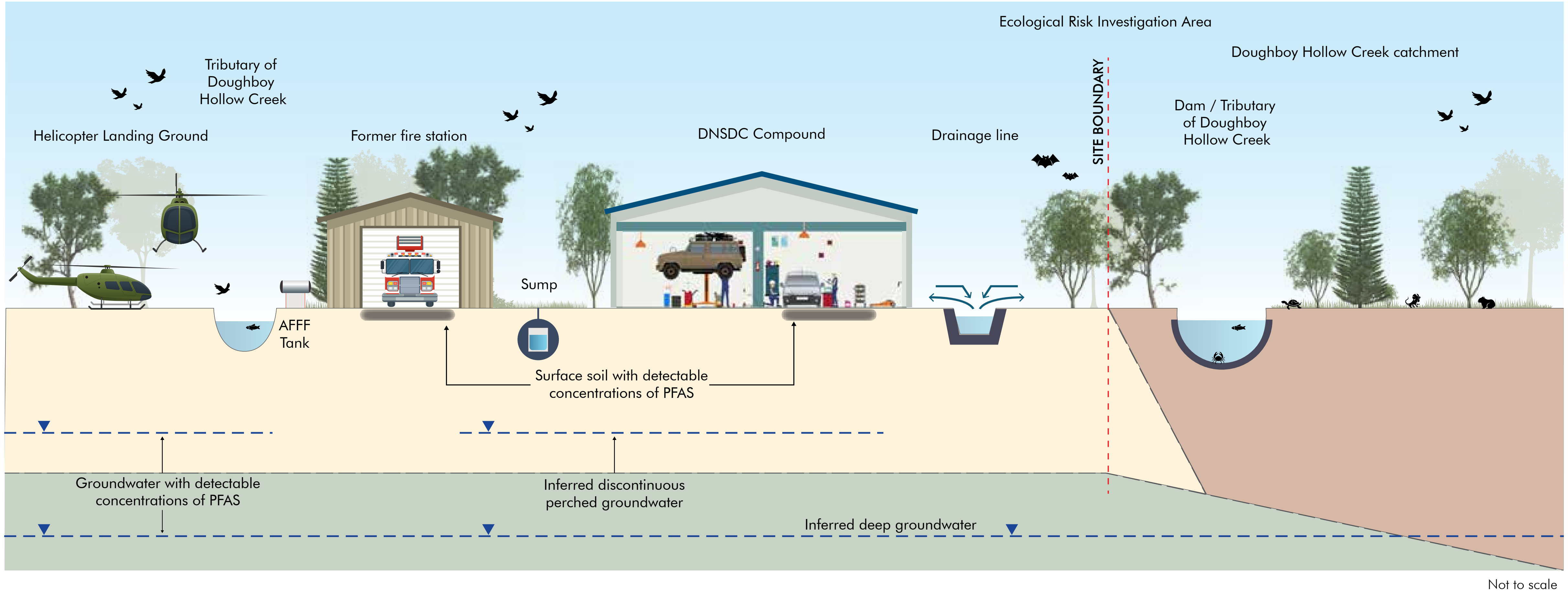
Interpretive Geology

Shale
Alluvial materials
Silt/Sand/Clay
Impacted soil
Impacted sediment

FIGURE 5

HUMAN HEALTH CONCEPTUAL SITE MODEL

Source: Department of Finance, Services and Innovation, 2019



Migration Pathways

Discharge or spilling of AFFF at the ground surface, sorption of PFAS to soil
Wind dispersion of PFAS impacted fine grained surface soil and dust if disturbed
Floodwaters disperse PFAS to soil
Surface water and sediment migration along drainage lines to catchment areas
Sorption of PFAS in surface water to sediment and re-solubilisation to surface water
PFAS in surface water used for irrigation
Discharge of effluent from sewage treatment plant to waterways
Uptake of PFAS into biota

Source	PFAS in groundwater	PFAS in soil	PFAS in surface water	PFAS in sediment & pore water	PFAS in biota
Ecological Receptor	No complete pathway between groundwater and ecological receptors identified	Terrestrial fauna including invertebrates, reptiles, mammals and birds Terrestrial flora	Aquatic fauna including fish, aquatic invertebrates, reptiles, mammals and birds Terrestrial fauna including invertebrates, reptiles, mammals and birds Aquatic and terrestrial flora	Aquatic fauna including fish, aquatic invertebrates, reptiles, mammals and birds Terrestrial fauna including invertebrates, reptiles, mammals and birds Aquatic flora	Aquatic fauna including fish, reptiles, mammals and birds Terrestrial fauna including reptiles, mammals and birds
Exposure Pathways		Fauna: Incidental ingestion of soil Flora: Uptake from soil	Fauna: Ingestion of surface water Dermal uptake (fish and invertebrates only) Flora: Uptake of surface water	Fauna: Incidental ingestion of sediment and pore water Flora: Uptake of pore water	Fauna: Ingestion of flora Ingestion of other fauna

Key

Groundwater
Surface water runoff

Interpretive Geology

Shale
Alluvial materials
Silt/Sand/Clay
Impacted soil
Impacted sediment

FIGURE 6
ECOLOGICAL CONCEPTUAL SITE MODEL

Source: Department of Finance, Services and Innovation, 2019

APPENDIX G References

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ATTACHMENT 1: ONGOING MONITORING PLAN

PFAS INVESTIGATION AND MANAGEMENT BRANCH

Singleton Military Area

PFAS ONGOING MONITORING PLAN

December 2021

GLOSSARY

AHD	Australian Height Datum
AS	Australian Standard
Base	A defined physical locality or geographical area from which Defence-related activities, operations, training or force preparations are managed, conducted, commanded or controlled.
COC	Chain of Custody
CSM	Conceptual Site Model
DO	Dissolved Oxygen
DSI	Detailed Site Investigation
DQI	Data Quality Indicators
DQO	Data Quality Objectives
EC	Electrical Conductivity
EPA	Environment Protection Authority (*or relevant state/territory jurisdiction)*
ERA	Ecological Risk Assessment
HEPA	Heads of EPAs Australia and New Zealand
HHERA	Human Health and Ecological Risk Assessment
LOR	Limit of Reporting
Management Area	The geographical area subject to Defence response actions
mg/kg	Milligrams per Kilogram
mg/L	Milligrams per litre
NATA	National Association of Testing Authorities
Off-site	Off-Base
OMP	Ongoing Monitoring Plan
On-site	On-Base
PFAS	Per- and polyfluoroalkyl Substances
PFAS NEMP	PFAS National Environmental Management Framework 2020 developed cooperatively between Australian jurisdictions
PFHxS	Perfluorohexane sulfonate
PFOA	Perfluorooctanoic acid
PFOS	Perfluorooctane sulfonic acid
PMAP	PFAS Management Area Plan
Project site	A defined site for construction and maintenance works within a Base
QA	Quality Assurance
QC	Quality Control

Remediation Action Plan (RAP)	Defines the purpose and objectives of the remediation, evaluates and determines the remediation options, and sets out performance measures.
Response actions	Actions identified as recommended or potential options to address potential risks
SAQP	Sampling and Analysis Quality Plan
Source area	An area within the Management Area that is, or has the potential to be, a source of contamination
SWL	Standing Water Level
TOC	Total Organic Carbon
TDI	Tolerable Daily Intake
TDS	Total Dissolved Solids
µg/L	Micrograms per Litre

1 INTRODUCTION

1.1 Preamble

This Ongoing Monitoring Plan (OMP) for per- and polyfluoroalkyl substance (PFAS) has been developed as part of the PFAS Management Area Plan (PMAP) for the Singleton Military Area (SMA). The location of the SMA is shown on Figure 1 in Appendix A.

The OMP defines a monitoring program designed to evaluate changes in PFAS concentrations in surface water and groundwater over time within the SMA Management Area. Changes may result from the specific or cumulative impact of remediation or containment actions, existing transportation trends, changes to hydrogeology or weather events. The OMP also aims to further improve the understanding of the extent of PFAS contamination at the SMA as well as the contribution of PFAS from on-site sources to both on and off-site groundwater and surface water bodies.

The following guidance has been considered in developing this OMP:

- National Environmental Protection (Assessment of Site Contamination) Measure 1999, as amended in 2013 (NEPC, 2013)
- PFAS National Environmental Management Plan, Version 2.0 (NEMP) (HEPA, 2020)
- Defence PFAS Framework – Construction and Maintenance Projects (Defence, 2019)
- Defence Contamination Management Manual, Annex L Guidance on Data Management (Defence, 2018).

1.2 Background

1.2.1 PFAS Uses and Health Impact

PFAS are a group of synthetic (i.e. ‘man-made’) compounds which include perfluorooctane sulfonate (PFOS), perfluorohexane sulfonate (PFHxS), and perfluorooctanoic acid (PFOA). PFAS have been widely used around the world since the 1950s to make products that resist heat, stains, grease and water. These include hydraulic fluid, stain resistant applications for furniture and carpets, packaged food containers, waterproof clothing, personal care products and cleaning products.

Due to the unique physiochemical properties of PFAS, this family of compounds is effective in extinguishing liquid fuel fires and therefore was used as an active ingredient in legacy aqueous film forming foam (AFFF). AFFF was used extensively worldwide by both civilian and military authorities from about the 1970s. Older formulations of AFFF contained a number of PFAS that are now known to be persistent in the environment and in humans.

Most people living in developed nations will have some level of PFAS in their body due to their widespread use. In June 2019, the Environmental Health Standing Committee (enHealth)[1], published guidance statements advising that although the scientific evidence in humans is limited, reviews and scientific research to date have provided fairly consistent reports of an association with several health effects. The health effects reported in these associations are generally small and within normal ranges for the whole population. There is also limited to no evidence of human disease or other clinically significant harm resulting from PFAS exposure at this time[2].

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[1] EnHealth is a subcommittee of the Australian Health Protection Principal Committee and is responsible for providing agreed environmental health policy advice. Its membership includes representatives from the Health portfolios of Australian and New Zealand governments.

[2] https://www1.health.gov.au/internet/main/publishing.nsf/content/health-pubhlth-publicat-environ.htm

However, due to the uncertainties in the current scientific evidence and since these chemicals remain in humans and the environment for many years, enHealth recommends exposure to PFAS be minimised wherever possible.

PFAS contamination on and in the vicinity of the Defence estate has arisen primarily because of the historic use of AFFF for training purposes or maintenance and testing of equipment or incident control.

1.2.2 The nature of PFAS

PFAS has many qualities that combine to present particular challenges in locating, containing and remediating PFAS contamination:

- water is the prime mode of PFAS contamination transferring from a source to a receptor - a person, animal, plant, eco-system, property or a waterbody
- most PFAS are highly soluble and mobile and can rapidly leach through soils or disperse in waterways, travelling long distances. This may sometimes reduce the level of contamination at the original source material
- PFAS can permeate the surfaces of some solid matrices. This includes concrete and other building materials, particularly used in storage tanks, fire training grounds and other large surface areas
- PFAS is chemically and biologically stable and has a low vapour pressure, so it is resistant to breakdown and evaporation. However, some longer chain PFAS do break down in the environment, and are precursors to forming PFOS, PFHxS or PFOA
- some PFAS (including PFOS and PFOA) are environmentally persistent and bioaccumulate. This means that some plants may be susceptible to PFAS uptake from soil and water. It then bio-accumulates and becomes a part of the food chain. The same process applies to some animals and fish.

1.3 Objective

The objective of the OMP is to set out a program of monitoring to continue to assess the changes in the nature and extent of PFAS within the environment. That is, where use of legacy AFFF has led to a potentially elevated risk to a receptor(s), or potential future risk to a receptor(s).

Data on changes in the distribution, concentration, transport (pathways and flow rates) and transformation of the contaminants and assessment of this data against appropriate guideline values. The dataset produced will provide:

- an evidence base for targeted and effective risk management of PFAS contamination to protect human health and environmental receptors
- an early warning that additional management of PFAS contamination may be warranted in areas not currently affected by PFAS.

1.4 Scope

The monitoring proposed in this OMP is primarily to evaluate changes in the nature and extent of groundwater, surface water and sediment in the SMA Management Area, specifically:

- monitor and evaluate changes in the nature and extent of PFAS in groundwater, surface water and sediment in the SMA Management Area
- monitor changes in PFAS in the catchments of the key surface water drainage lines from the SMA including Doughboy Hollow Creek, Emigrant Creek and Mudies Creek
- monitor changes in PFAS concentrations in groundwater in and near PFAS source areas on and

off-base
- monitor changes in PFAS concentrations in groundwater along and near the northern boundary of the Cantonment to act as a sentinel system for PFAS migration across the Base boundary
- collect data to further refine the understanding of the contribution of PFAS from the SMA to offsite surface water, including the Singleton Sewage Treatment Plant (STP), and groundwater.

Where relevant, the data collected will also be used to support the ongoing evaluation of management actions outlined in the PMAP, however additional data may be required to support such an evaluation. This could include:

- development and implementation of a Sampling and Analysis and Quality Plan (SAQP) for a data gap assessment, mass flux study and remediation feasibility study
- a remediation action plan for implementation of a management response
- a validation plan following the implementation of a management response.

This OMP document also provides the following:

- an outline of the site setting, including the Management Area, to provide a context to the monitoring program (Section 2.0)
- details of the monitoring program including data quality objectives, sampling locations, sampling frequency and analytical analysis (Section 3.0)
- reporting requirements (Section 4.0)
- requirements for monitoring of management measures and potential future risks, and triggers for the review of this OMP (Section 5.0).

1.5 Document Review

The science of understanding PFAS impacts and ways of managing PFAS contamination are constantly evolving. There is still a lot that is not established about the behaviour or impacts of PFAS contamination on human health and the environment.

This OMP has been prepared based on information available at the time of writing and relies on the findings of the Detailed Site Investigation Report (DSI [AECOM, 2019]), DSI Addendum (AECOM, 2021a), Human Health and Ecological Risk Assessment (HHERA [AECOM, 2021b]) and strategic management of risks assessed in the PMAP. Defence recognises that there may still be gaps in information that will be progressively addressed while impacted sites are being managed.

This document will be reviewed and updated in accordance with the strategy detailed in Section 5.

1.6 Constraints and Assumptions

This document has been developed on the basis of the following assumptions:

- the state of knowledge presented within the DSI completed in December 2019 (AECOM 2019), the DSI Addendum completed in January 2021 (AECOM, 2021a) and the HHERA (AECOM, 2021b), including:
  - historical use of AFFF at the SMA
  - PFAS results (on and off-Base)
  - conceptual site model
  - community surveys.

- proposed management / remediation options are based on the current technology available at the time of writing this document

- the OMP focusses on monitoring of general changes and variability in the nature and extent of PFAS contamination in the medium to long term. Specific sampling requirements to investigate or validate remediation actions are not addressed in this OMP
- Government issued guidelines, advisories and policies issued during the assessment of PFAS at the SMA, such as the PFAS NEMP (2020)
- the understanding of infrastructure developments within the SMA Management Area at the time of this OMP
- access to private properties will be minimised where publicly accessible alternatives are available, to minimise inconvenience for landowners
- access to private properties, where required, will be granted by landowners
- the proven technologies are suitable for the conditions at the Base and surrounds.

2 SITE SETTING

2.1 Base Description

The Management Area comprises the Singleton Military Area (SMA), the Singleton Sewage Treatment Plant (STP) located off-Base and neighbouring properties to the north, north west and north east.

The SMA is comprised of Lone Pine Barracks (the Cantonment) and the Singleton Training Area (STA). The SMA is located approximately 8km south of the township of Singleton. The barracks houses the School of Infantry, Joint Logistics Unit East (Hunter Valley), the Australian Army Infantry Museum as well as Estate & Infrastructure Group SMA. Support activities undertaken primarily at the Barracks include vehicle maintenance, storage and distribution of fuels and equipment wash-down. A fire station was operational at the Barracks between 1963 and 1994, and associated activities included and historical firefighting training with AFFF and equipment maintenance and testing.

The STA is an approximately 15,000 hectare firing range located between the Cantonment (to the north), Brokenback Range (south), the Hunter Vineyards (east), and the Mount Thorley Mine area (west). The STA is comprised of a number of former and active ranges for weapons firing, vehicle training and explosives testing.

2.2 Site Setting

2.2.1 Climate

The climate at the SMA is characterised as temperate, with cool winters and warm summers. Winter months (May – October) are typically drier than summer months (November – April). Rainfall has been monitored on-site at Bureau of Meteorology (BOM) Station 61430 since 2017. Average annual rainfall measured at the BOM Station with a long record at Broke (Station number 61100) is approximately 7 km away from the SMA.

Rainfall monitored on-site at BOM station 61430 between January 2018 and June 2020 is presented in the HHERA (AECOM, 2021b). This indicates that rainfall prior to the Preliminary Site Investigation (PSI) sampling period in October 2018 was below average. The comprehensive surface sampling round conducted in April 2019 as part of the DSI (AECOM, 2019b) was in response to the moderate rainfall received in March 2019. A moderate amount of rainfall was also received between January and April 2020, allowing formerly dry ephemeral waterbodies to flow again and to be sampled as part of HHRA and ERA fieldwork (as required).

2.2.2 Topography

The SMA is located approximately 40 kilometres east of the Great Dividing Range and is dominated by moderate to gently sloping hills, with the foothills of the Brokenback Ranges rising steeply at the southern extent of the STA.

The topographic zone assigned to the majority of the off-Base Investigation Area is the Central Lowlands, which are located along the Hunter River and typified by undulating to rolling hills on weak sedimentary rocks.

2.2.3 Surface Water

The Management Area spans the catchment areas of several creek lines that ultimately drain north and eastwards to the Hunter River located approximately 2 km from the SMA's northern boundary. The key on-Base drainage lines investigated as part of the DSI (AECOM, 2019b) include:

- Mudies Creek and Emigrant Creek, which are located along the western and eastern boundaries of the Dochra airfield at the STA
- Peach Tree Creek, Monkey Place Creek, Loder Creek, Nine Mile Creek, Rothbury Creek and Jump-up Creek, which emanate from the STA but are not located within the areas assessed by the HHERA (AECOM, 2021b). These watercourses were assessed in the PSI (AECOM, 2019a) and, based on non-detection of PFAS and lack of identified source areas, were not considered further during the DSI or HHERA.
- Doughboy Hollow Creek, which traverses both the Cantonment and the STA, and then runs in a northerly then easterly direction off-Base along the western and northern SMA boundaries respectively.

Doughboy Hollow Creek and a number of its tributaries traverse the Cantonment and are connected to engineered drainage channels. The DSI (AECOM, 2019b) divided the catchments of the Cantonment into three sub-catchments (as presented on Figure 3A in Appendix A) as follows:

- Sub-catchment A (refer to Figure 3): Northern portion of the Cantonment. The primary drainage line is an un-named tributary of Doughboy Hollow Creek which flows in a northerly direction and discharges off-site at the northern Cantonment boundary. In addition to runoff via defined the unnamed tributary of Dough Boy Hollow Creek, surface water runoff from the Cantonment during heavy rainfall events may occur via overland flow. Notably, runoff generated at the DNSDC (located within sub-catchment A) appears to drain north towards the northern boundary of the site via overland flow before crossing beneath the railway line and entering a dam within Council-owned land
- Sub-catchment B (refer to Figure 3): Central portion of the Cantonment. The primary drainage line is an un-named tributary of Doughboy Hollow Creek which flows in a north-westerly direction and discharges off-site at the western Cantonment boundary down-gradient of the HLG
- Sub-catchment C (refer to Figure 3): Southern portion of the Cantonment. The primary drainage line is the main watercourse of Doughboy Hollow Creek which flows in a north westerly direction and discharges off-site at the western Cantonment boundary in the vicinity of the landfill and former flame thrower range.

Doughboy Hollow Creek flows from across the western boundary of the Cantonment (sub-catchment C), then flowing in a north / north-westerly direction (within the Investigation Area), then turning north east towards Army Camp Road north of the Cantonment.

Whilst a shallow drain continues east towards a culvert under Army Camp Road, AECOM observed during the DSI (AECOM, 2019b)[3] that surface water was not present at this location, and it was inferred that the creek, on most occasions, soaks through the alluvial soils, providing recharge to groundwater. The dam on the eastern side of Army Camp Road therefore appears to primarily receive inputs from sub-catchment A via a tributary of Doughboy Hollow Creek that leaves the Cantonment at the northern boundary.

The Doughboy Hollow floodplain, including lower portions of the Whittingham area, and part of the wider Hunter River Alluvial floodplain, is understood to be prone to waterlogging and flooding during heavy rainfall events. Review of aerial imagery of surface water flow paths following a flood event in January 2016, indicated that following periods of heavy rainfall, Doughboy Hollow Creek can flood large portions of the off-Base Investigation Area, forming continuous flow paths between Doughboy Hollow Creek at the Cantonment and the wetland east of the STP.

The wetland east of the STP is understood to have hydraulic connectivity with groundwater present within the Hunter River alluvial floodplain at Whittingham. Therefore, surface water that migrates from Doughboy Hollow Creek to the wetland area east of the STP may provide recharge of groundwater present in the Hunter River alluvial floodplain.

[3] During the DSI as well as part of the proposed sampling of ERA-24, which was observed to be dry (Refer to **AECOM, 2021a**).

It is noted the DSI (AECOM, 2019b) was completed during a period of drought and hydrological observations were limited due to the absence of surface water within the Investigation Area. Additional inspections completed during the HHERA (AECOM, 2021b) and the supplementary sampling program (AECOM, 2021a) were undertaken during relatively wetter climatic conditions and observations confirmed:

- Doughboy Hollow Creek does not continue downstream of the culvert at Army Camp Road and appears to soak away to alluvial soils.
- The dam on the eastern side of Army Camp Road (downstream of the culvert) primarily receives inputs from the unnamed tributary of Doughboy Hollow Creek that drains sub-catchment A. The tributary leaves the Cantonment at the northern boundary and flows through location HHRA36 (refer to AECOM, 2021a) before reaching the dam.

Mudies Creek and Emigrant Creek flow off-site from the northern boundary of the STA and meet to the east of the Cantonment, with Mudies Creek continuing north-east towards the Hunter River.

Other than Doughboy Hollow Creek, Emigrant Creek and Mudies Creek, off-site waterbodies within the Management Area include a number of private dams and smaller drainage lines located on residential properties. In addition, an area of Council land east of the STP was observed to be largely inundated during the DSI (AECOM, 2019b), with the water considered to be at least partly sourced from discharges from the STP. This area was subject to a survey by an aquatic ecologist from Austral as part of the ERA (AECOM, 2021b) sampling program. The ecologist described this area as a wetland[4] situated in an agricultural landscape that is regularly grazed by cattle (refer to AECOM, 2021b). Council has advised that treated water from the STP is continuously discharged into the Doughboy Hollow Creek water course directly north of the STP.

Aerial imagery of surface water flow paths following a flood event (refer to AECOM, 2021b) illustrates that following periods of heavy rainfall, Doughboy Hollow Creek floods large portions of the off-site Management Area, forming continuous flow paths between Doughboy Hollow Creek at the Cantonment and the wetland east of the STP. Downstream of the wetland area, water flow continues via Doughboy Hollow Creek, flowing in a south-easterly direction and meeting Mudies Creek outside the Management Area. These surface water flow paths are presented on Figure 3 in Appendix A. Given its ephemeral nature, during periods of low rainfall, Doughboy Hollow Creek is unlikely to extend to the northern portions of the Management Area or be continuous with Mudies Creek.

During previous investigations all the major surface water bodies were observed to be ephemeral across the SMA and off-Site Management Area over the course of the AECOM field program from 2018 to 2020. These surface water bodies flow in response to rainfall with no baseflow component connected to regional groundwater, with the exception of the continuous flow paths between the wetland east of the STP and Doughboy Hollow Creek, which are recharged by the continuous discharge from the STP.

Sampling activities undertaken as part of the PSI (AECOM, 2019a) were completed during a period of drought so surface waters generally comprised stagnant, disconnected pools of water which hindered the collection of surface water at many locations. More rainfall was recorded during the DSI (AECOM, 2019b); however, the observations were generally consistent with the PSI, with sample locations having little to no surface water flow. Significant rainfall was encountered prior to HHRA and ERA sampling, allowing surface water flows to be observed.

There is a potential for surface water to recharge groundwater in the Management Area. A review of major ion composition completed for 55 groundwater and five surface water samples as part of the DSI (AECOM, 2019b) found that surface water is reasonably distinct from groundwater, with surface water samples reporting a much lower dissolved ion content, much lower electrical conductivity (EC)

[4] Department of Agriculture, Water and the Environment classifies a "wetland" as an area of land where water covers the soil all year or just at certain times of the year. These areas include, but are not limited to, swamps, marshes, lakes, mangroves and bogs (DoAWE, 2020).

and lower cation concentrations. Therefore, available data indicate that surface water and groundwater interaction is likely to be limited, with surface water appearing to be relatively fresh and fed directly by rainfall. All the samples (except one groundwater sample) reviewed in the DSI (AECOM, 2019b) as part of this exercise were collected from the site, and therefore these conclusions apply to the site only (not off-Site areas).

Key surface water drainage features are shown on Figure F3 in Appendix A.

2.2.4 Flora and Fauna

The EPBC Protected Matters Search Tool (PMST) (DoEE, 2020) search within 5 km of the Management Area identified 41 listed threatened species, notably the following species or species habitat which are known to occur:

- Birds: the regent honeyeater[5] and swift parrot[6] are critically endangered
- Mammals: the spot-tailed quoll[7] is endangered
- Plants: *Euphrasia arguta* (annual herb) and *Prasophyllum* sp. *Wybong* (terrestrial orchid) are critically endangered
- Reptiles: the broad-headed snake is vulnerable.

This is in addition to a range of species identified to potentially occur in the area.

The following fauna have been observed by AECOM field staff within the Investigation Area[8] (as defined in the HHERA):

- Numerous birds, including small eagles, falcons, black cockatoos and tawny frogmouth owls. A wedge-tailed eagle was observed at the Dochra Airfield, with three breeding pairs previously identified on the STA by site staff
- Kangaroos across the Investigation Area
- Wild horses across the STA
- Wild dogs, wild boars and foxes at various locations across the STA (considered to be pests with low ecological value)
- Tadpoles and frogs at numerous locations across the Investigation Area
- Goannas, including a lace monitor (approximately 1.5 m in length) at the Cantonment
- Frilled-neck lizard at the Cantonment
- Red-bellied black snake centrally within the STA
- Possum within the Dochra Airfield
- Small tortoise on the boundary between the Cantonment and the STA
- Turtle within an off-site drainage line east of the Cantonment
- Crab legs at Mudies Creek within the Dochra Airfield.

An ecological survey of terrestrial habitats completed as part of the HHERA, identified one threatened species: the River Red Gum, whose Hunter population is listed as endangered under the BC Act, was observed at the ERA-2 survey area at the Cantonment. No threatened fauna species were observed,

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[5] The regent honeyeater primarily feeds on nectar and other plant sugars. It can also feed on insects and spikers as well as native and cultivated fruits.

[6] The swift parrot mainly feeds in the canopy of flowering eucalyptus, eating mainly nectar as well as phyllids, lerps, seeds and flowers

[7] The spotted quoll's diet comprises small mammals (such as gliders and possums), reptiles, invertebrates, birds and eggs,

[8] During the PSI (AECOM, 2019a), DSI (AECOM, 2019), field visit by ecological risk assessment team (AECOM, 2019c) and fieldworks undertaken as part of this HHERA.

and a habitat assessment performed by NGH noted that threatened amphibian species are considered unlikely to occur within the surveyed areas (AECOM, 2021b). Fauna opportunistically observed during the terrestrial survey include the following:

- Noisy miner
- Australian raven
- Brush-tailed possum
- Eastern grey kangaroo
- Australian wood duck
- Yellow-tailed black cockatoo.

The ecological survey of aquatic habitats identified a range of aquatic invertebrates at surveyed locations, including lower trophic level species (e.g. gastropods) and higher trophic level species (e.g. yabbies). The aquatic survey additionally identified a range of finfish, including lower trophic level species (e.g. gambusia) and higher trophic level species (e.g. eel). A range of emergent and submergent macrophytes (aquatic plants) were also identified at each sampling location. A spotted marsh frog was identified in the wetland east of the Singleton STP.

2.2.5 Regional Geology

The SMA and surrounding land is located within the northern part of the Sydney Basin which is characterised by Permian and Triassic aged sediments. The sediments are predominately fresh water with some marine, terrestrial and coal deposits. The predominant lithology at the Site is Narrabeen Group which is composed of sandstone with some conglomerate, claystone and shale. Other rocks present are quartzose sandstone of the Hawkesbury Sandstone, siltstone and tuff. Coal measures are also extensive consisting of black coal interbedded with sandstone, shale mudstone, conglomerate with minor chert and tuff.

The SMA is covered by a diverse range of soil types, as identified from the Soil Landscapes of Singleton 1:250,000 sheet, (Kovac, M. and Lawrie J. 1991). The soils within low-lying parts of the Management Area consist principally of alluvial soils, yellow and red podzolic soils. In the more elevated areas to the south the soil profiles are more shallow and are classified as shallow soils. Quaternary alluvial deposits of gravel, sand and silt and clay are most pronounced along the floodplain of the Hunter River (for which Doughboy Hollow floodplain is a part).

2.2.6 Hydrogeology

The hydrogeology of the Management Area can be divided into several notable subunits:

Perched Groundwater unit

Unconfined discontinuous perched groundwater within the sediments flanking creeks. Groundwater is present within discontinuous alluvium/colluvium flanking major water courses across the Management Area. The groundwater is perched and recharged by rainfall in the catchment, though storage is extremely limited due to the shallow and narrow nature of the alluvial/colluvial material. The zone of saturation would periodically dry out following extended periods of low rainfall and is susceptible to contamination due to its unconfined nature and transmissive properties. Groundwater in this unit ranges from 2 to 25 metres below top of casing (m BTOC).

Alluvial Groundwater

Groundwater is present in the low-lying part of the Management Area to the north-west, north and north-east of the Site within the alluvial sediments of the Hunter River floodplain. Groundwater is predominantly recharged from surface water and from the Hunter River and its tributaries, and locally enhanced by rainfall runoff and infiltration.

High yields of good quality water can be pumped from the aquifer making it a resource for beneficial uses including irrigation, agriculture and farming.

Shallow Groundwater unit

Shallow perched groundwater within the weathered zone of Permian bedrock. Groundwater is ephemeral with its presence being reliant on rainfall. The groundwater becomes perched above zones of low hydraulic conductivity such clay or shale lenses within the clayey lithology. The presence of groundwater is dependent upon structures within the geological sequence where water can become perched groundwater levels are highly variable. Additionally, local variations in relief (i.e. dip direction of the bedding) at the soil/bedrock interface may add further complexity to groundwater mobility and flow direction. Groundwater quality is expected to be poor due to the leaching of salts from the Permian bedrock. Perched groundwater sitting in the unconsolidated material above the shale bedrock, is discontinuous in nature, but generally flows in a north/north-easterly direction towards the Hunter River.

Deep Groundwater unit

The dominant bedrock aquifer across the site; forms the regional aquifer. Groundwater flow through the aquifer is highly variable depending primarily on rock porosity and interconnection of void space between grains of the rock, and secondarily on structural features such as joints, fractures, bedding layers and shear zones. Groundwater flow through the aquifer is highly variable depending on the lithological conditions and the degree of fracturing. The coal layers contain a large volume of groundwater. Groundwater quality is generally poor, with salts leaching from the sedimentary rocks.

The regional groundwater in the shale bedrock at the Cantonment was shown to flow in a north/north-easterly direction towards the Hunter River (AECOM, 2021a). Shallow groundwater sitting in the unconsolidated material above the shale bedrock, is discontinuous in nature, but generally flows in a north/north-easterly direction towards the Hunter River.

At the STA, around Dochra Airfield, the regional groundwater in the shale bedrock flows in a northerly direction towards the Hunter River.

2.2.7 Current and Projected Land Uses on and Surrounding the Management Area

Current Land Uses

The uses of land surrounding the SMA are summarised in **Table 1**. It is anticipated that the land uses surrounding SMA will remain reasonably similar for the foreseeable future. However, any new information pertaining to changes in land use could trigger a review and/or update of the HHERA (AECOM, 2021b).

Additionally, it is noted that there is the potential that off-property activities and/or businesses may have used or generated wastes containing PFAS for various purposes.

Table 1: Land Uses surrounding the Singleton Military Area

Direction	Description
North	The Cantonment is bounded by grazing land within Doughboy Hollow and the floodplain areas of Whittingham and Glenridding. A STP owned by Singleton Council is located within Doughboy Hollow. Further to the north lie the township of Singleton and the Hunter River. The Whittingham Rural Fire Station and Whittingham Airstrip are located 1 km and 0.6 km north east of the Cantonment, respectively.

South	The STA is bounded to the south by the rugged terrain of the Pokolbin State Forest and the Brokenback range. Further to the south east are the Hunter Valley vineyards of Pokolbin.
East	Rural and semirural land holdings including pastureland and sparsely wooded open land. The Hunter River lies to the north east. Irrigated cropland dominates within the floodplains of the Hunter River.
West	The western boundary of the Cantonment is bounded by grazing land within the Doughboy Hollow, and irrigated cropland within the floodplains of the Hunter River. Further west are the Mount Thorley/Warkworth and Bulga Open Cut coal mines and associated buffer areas.

2.3 Extent of Contamination

This section provides a high-level summary of the identified PFAS sources at the SMA and the migration mechanisms that are present. More detailed information is available in the DSI (AECOM, 2019), DSI Addendum (AECOM, 2021a) and HHERA (AECOM, 2021b). The nature, extent, fate and transport of the contamination within the Management Area are based on the DSI (AECOM, 2019b) and DSI Addendum (AECOM, 2021a) included five PFAS source areas were identified following the DSI (AECOM, 2019). These areas were:

- Former Cantonment Fire Station and fire training pits (PFAS in soil, surface water, groundwater and concrete)
- Defence National Storage and Distribution Centre (DNSDC [PFAS in soil, groundwater, surface water and sediment])
- Alternate Landing Ground (ALG [PFAS in soil, surface water and sediment])
- Dochra Airfield (PFAS in soil, groundwater, surface water and sediment)
- Helicopter Landing Ground (HLG [PFAS in soil, groundwater, surface water and sediment]).

The discharge of AFFF (3M Lightwater) to land is suspected to have occurred at these areas during routine operations, maintenance and training exercises.

Reported concentrations of PFAS were generally below relevant direct contact health and ecological guidance values for potentially active exposure pathways (ways that people or the environment could be exposed to PFAS). Exceptions were at the area surrounding the Former Cantonment Fire Station where several exceedances of health-based guidance values (for residential and public open space land uses) and at several source areas for ecological guidance values.

The spatial distribution of PFAS detections in groundwater is limited and, in some cases isolated, and it is considered unlikely that groundwater migration is a significant transport mechanism off-site. Refer to figures 5A and 5B for plume representation and Figure 6 for groundwater flow direction.

Surface water flow (including areas of overland flow) is considered to be the primary PFAS migration pathway from the Site. Surface water run-off from the source areas has resulted in the detectable concentrations of PFAS flowing into catchment drainage lines, as well as absorbing into soils and sediments in the drains and creeks. Detectable concentrations of PFAS were measured in surface water and sediment samples collected from creek lines within SMA. Detections were also found at locations where surface water discharges from the SMA.

As discussed in Section 2.2.7 there is the potential that off-property activities and/or businesses may have used or generated wastes containing PFAS.

2.4 Water Use

There are currently no restrictions on the beneficial use of extracted groundwater within the Investigation Area (as defined in the DSI [AECOM, 2019], DSI Addendum [AECOM, 2021a] and HHERA [AECOM, 2021b]) although there are licensing/approval requirements.

A search of registered bores identified more than 100 bores within 2 km of the SMA listed as being used for household water supply, irrigation or livestock watering. Water use surveys conducted during the DSI (AECOM, 2019) and HHERA (AECOM, 2021b) found that of the 47 respondents who live within the Investigation Area, nine used bore water at their properties at the time of responding to the survey. No respondents indicated that bore water was used as a drinking water source at the property.

The main observations from the water use surveys included:

- the primary source of water in the off-site Investigation Area is from mains water supply or rainwater tank connection
- groundwater is abstracted and used at properties for non-potable domestic supply
- nine respondents indicated that they use the dams and / or creeks on their property for recreational purposes
- 19 respondents indicated that they abstracted water from dams and / or creeks on their property for irrigating crops and / or watering livestock.

2.5 Risk Findings

Human Health

Potential risks have been identified for people who live within the Investigation Area (as defined in the HHERA [AECOM, 2021b]), and who eat a large proportion of their diet sourced from:

- **Ingestion of home-grown red meat** from sheep or cattle that have consumed water containing detectable PFAS, or have grazed in areas irrigated or flooded with water containing detectable PFAS
- **Ingestion of home-grown milk** from cows that have consumed water containing detectable PFAS, or have grazed in areas irrigated or flooded with water containing detectable PFAS
- **Cumulative ingestion of home-grown red meat, of home-grown milk** from cows from sheep or cattle and **of eggs** from home-grown backyard poultry that have consumed water containing detectable PFAS, or have grazed / roamed in areas irrigated or flooded with water containing detectable PFAS.

Drinking groundwater may present a future risk to off-Site users of groundwater (it is not known to currently occur), should the land use change and groundwater extraction occur near the SMA. It is noted that groundwater is not currently known to be used for drinking water supply within the Investigation Area (as defined in the HHERA [AECOM, 2021b]). As drinking of groundwater is not currently known to occur it has not been assessed in this document, however, should the land use change in the future this risk may need to be addressed.

Ecological Risk

The ecological risk assessment (ERA, AECOM [2021b]) concluded that based on the available data presented and the uncertainties identified, the outcomes of the ERA indicate that there is low to minimal potential for direct or indirect risks to ecological receptors from exposure to PFAS in the ERA. Thus, no site management measures are considered necessary to abate PFAS exposure to ecological receptors within the Investigation Area.

2.6 Drivers and Constraints

Key drivers and constraints impacting upon delivery of the OMP include:

- access to private land to sample surface water or groundwater may present a constraint so sampling locations on Defence or public land have been preferentially selected
- effective stakeholder engagement
- implementation of management options at source areas may destroy monitoring well locations or prevent safe access to certain locations. This will be considered as management actions are implemented and the OMP is updated
- the ephemeral nature of water courses may impact on the ability to obtain surface water samples. This will be considered further by the OMP Service Provider in preparation of the SAQP.

The risk assessment findings (off-site risks as assessed in the HHERA) remain as low and acceptable, excluding people who live within the Investigation Area and who eat a large proportion of their diet sourced from home-grown red meat and/or home-grown milk (AECOM, 2021b).

2.7 Communications

The following will be shared with relevant local, State and Commonwealth authorities and made publicly available:

- OMP
- Monitoring data collected during the implementation of the OMP
- Decisions made in response to the data collected during implementation of the OMP
- Changes to the OMP in response to incoming data over the implementation period.

2.8 Related Management Actions

One or more specific remediation action plans (RAPs) may be developed for the Management Area in the future, as specified in the PMAP. Future RAPs will contain specific on-going monitoring actions to assess and validate the impact of that remediation plan. Where appropriate synergies will be evaluated between this OMP and any future RAP or data gap assessments.

Consideration should also be given to other management actions or relevant work, such as asset redevelopment programs, undertaken to manage risk, such as Interim Response Management Actions that may not have RAPs but may have relevant Interim Response Management Action Plans, or similar.

2.9 PMAP Review and Update

Ongoing implementation of the PMAP (including the OMP) will be subject to continuing annual review and update, to ensure documentation remains current and relevant, and reflects the results of the OMP and advances in information and technology (based on ongoing technology and performance assessment and review). As described in Section 2.7, where changes to the PMAP and/or OMP occur, they will be communicated and discussed with the community and other stakeholders, including relevant local, State and Commonwealth government authorities.

3 ONGOING MONITORING PROGRAM

The OMP monitors changes to the identified PFAS contamination plume(s) (refer to Figures 5A and 5 B in Appendix A) and surface water contamination characteristics in the SMA Management Area.

Changes may result from the specific or cumulative impact of remediation or containment actions, existing transportation trends, changes to hydrogeology, or weather events.

All Defence PMAPs have included an OMP as a mandatory response action.

3.1 Sampling, Analysis and Quality Plan (SAQP)

An SAQP will be developed prior to implementation of the OMP. The document will be prepared by the OMP Service Prover and reviewed by Defence prior to commencement of works to ensure consistency with the program in line with any changes in documentation, including ongoing review of the OMP and PMAP.

Further guidance is provided in Appendix B for development of a site specific SAQP.

3.2 Data Quality Objectives

Data Quality Objectives (DQOs) are qualitative and quantitative statements derived from the outputs of the first six steps of the seven step DQO process that:

- clarifies the study objective
- defines the most appropriate collection of data as relevant to the study objective
- determines the conditions from which to collect data
- specifies tolerable limits on decision errors, which will be used as the basis for establishing the quantity and quality of data, needed to support the decision.

The DQOs that will be adopted for this OMP will be prepared in line with the DQO process outlined in US Environmental Protection Agency (EPA) (2006) and NEPM 2013 (Schedule B2) and are presented in the seven-step DQO approach, Section 3.2.1.

3.2.1 NEPM DQO Seven Step Process

Table 3-1 NEPM DQO 7 Step Process

Process	Description
Step 1: State the problem	PFAS source areas at the SMA are contributing to the presence of PFAS in surface water and to a limited extent groundwater off-property. Defence and State regulatory agencies require up-to-date data to assess the ongoing nature and extent of PFAS in the management area, assess the performance of implemented management actions and enable informed risk management decisions to protect human health and the environment. The data collected by implementing this OMP will provide a periodic / longitudinal dataset that can be used to assist with assessment of temporal changes in PFAS concentrations in groundwater and surface water / sediment on- and off-site as well as assessing relative mass flux of pathways and how groundwater and surface water levels respond to natural fluctuations. The OMP will continue for a nominal period of 3 years and cover the primary implementation period of the PMAP in which PMAP remediation actions (or other short-medium term actions) are likely to be completed. The need for ongoing monitoring following this period will be assessed with advice from NSW Government.
Step 2: Identify the decision/ goal of the study	The goal of the study is to establish a systematic routine groundwater and surface water / sediment sampling and analysis program to: • Refine current understanding of the distribution of PFAS in groundwater and surface water/sediment in the Management Area • Monitor changes to PFAS distribution and variability due to management actions and seasonal variations • Collect additional data to inform future management actions. This will allow decisions to be made regarding the assessment of risks to human and ecological receptors into the future (for example, updating the conceptual site model), and whether the OMP needs to be amended to reflect these updates.
Step 3: Identify the information inputs	To allow assessment of the data against the study goal listed in Step 2 above, the following inputs will be considered: • PFAS results from previous environmental investigations including the DSI (AECOM, 2019), DSI Addendum (AECOM, 2021a) and HHERA (AECOM, 2021b), and the residential sampling program, where permission to use the data has been granted by landowners. • Groundwater and surface water flow regimes identified in the DSI (AECOM, 2019) and DSI Addendum (2021a). • Meteorological data including rainfall. • Groundwater, surface water and sediment data collected and analysed for PFAS, as part of this OMP. • Advances in laboratory analytical approaches and changes in regulatory requirements. •

Process	Description
Step 4: Define the boundaries of the study	The spatial and temporal boundaries that apply for data collection are detailed below and will influence the decision-making process for ongoing monitoring: • The spatial boundary for data collection and decision making is limited to the on-site and off-site Management Area, however is subject to change with input from the NSW Government • The sampling completed as part of the OMP will be limited to groundwater, surface water and sediment, at the frequencies defined in Section 3.4 • The monitoring will be long term (initial period of 3 years) and potentially ongoing, based on review of the data and refinement of the OMP, as appropriate.
Step 5: Develop the analytical approach/decision rules	The decision rules can be defined as: **Analytical:** • Analytical selection; all samples will be analysed for the extended PFAS suite and selected media (groundwater and surface water) for major cations/anions and metals • Analytical method selection for PFAS is based on achieving appropriate laboratory Limit of Reporting (LOR) in the various media to be analysed • If the sample / laboratory quality assurance / quality control data are within the acceptable ranges, the data will be considered suitable for use. **Project:** • Sample locations have been selected with the objective of monitoring PFAS trends (temporal and seasonal), providing early warning of changes in the migration of PFAS in the Management Area in surface water and groundwater, and to assist with refinement of Management Area boundary over time, as required • If PFAS concentrations are reported above the laboratory LOR, where it was previously <LOR, then it will be considered whether further assessment of the data will be required (refer to Table 4-3) • If the PFAS is reported at a concentration that is above drinking water guideline in groundwater, then it will be considered that further assessment is required and / or notification (refer to Table 4-3) • If the PFAS is reported at a concentration that is inside a trigger value or acceptable range, then it will be considered whether monitoring is continued or reduced, this assessment will be undertaken after two years of monitoring (refer to Table 4-3).

Process	Description
Step 6: Specify performance or acceptance criteria	Specific limits for the works included in the OMP are in accordance with the appropriate guidance made or endorsed by state and national regulations, appropriate indicators of data quality, and standard procedures for field sampling and handling. This step also examines the certainty of conclusive statements based on the available new data collected. This should include the following points to quantify tolerable limits: • A decision can be made based on a certainty assumption of 95% confidence in any given data set. A limit on the decision error will be 5% that a conclusive statement may be a false positive or false negative • A decision error in the context of the decision rule presented above would lead to either underestimation or overestimation of the risk level associated with a particular sampling area • Sampling errors may occur when the sampling program does not adequately detect the variability of a contaminant from point to point across the site. To address this, the OMP outlines minimum numbers of samples proposed to be collected from each media • As such, there may be limitations in the data if aspects of the OMP cannot be implemented. Some examples of this scenario include but are not limited to: - Proposed surface water or groundwater sample locations may be dry at the time of sampling - Proposed groundwater well locations are damaged or destroyed and therefore cannot be sampled - Proposed samples are not collected due to access being restricted to a given location. • Limitations in ability to acquire useful and representative information from the data collected. The data are proposed to be collected from multiple locations and sample media. Some examples of this scenario include: - Some of the data are proposed to be collected from landholder bores, which are not purpose-built for groundwater monitoring. In some cases, there is limited information on the bore construction, and the likely presence of dedicated pumps or windmills may prevent groundwater depths being accurately recorded while also preventing groundwater being sampled using low flow techniques. • Measurement errors can occur during sample collection, handling, preparation, analysis and data reduction. To address this the following measures are proposed: - Collection of sufficient sample mass to facilitate analysis reported to standard laboratory detections limits. Collection of insufficient sample mass may result in raised detection limits - Field staff to follow a standard procedure when collecting samples, including decontamination of tools, and use of appropriate sample containers and preservation methods - Laboratories to follow a standard procedure when preparing samples for analysis and undertaking analysis - Laboratories to report quality assurance/ quality control data for comparison with the DQIs established for the OMP.

Process	Description
Step 7: Develop the plan for obtaining data	The methodology presented in this OMP is designed to meet the objectives described in Section 1.2 and to achieve the nominated DQOs. Optimisation of the data collection process will be achieved by: • Working closely with the analytical laboratories and sampling equipment suppliers to ensure that appropriate procedures and processes are developed and implemented prior to and during the fieldwork, to ensure that sample handling, and transport to and processing by the analytical laboratories is appropriate • Conducting sampling in accordance with the NEMP (HEPA 2020), with specific reference to Section 18.5 - *Considerations for Specific Environmental Media* • Basing the sampling upon a CSM developed using the information available at the implementation of the OMP. Updating the CSM as new data becomes available in the course of the implementation of the OMP, as required • Progressive review of the data and modification of sampling programs to optimise the value of data generated. If the objectives of the OMP are not being met, the sampling design and approach will be reviewed and amended, as required. More specific details will be provided in the SAQP developed by the OMP Service Provider.

3.3 Proposed Monitoring Intervals

Groundwater, surface water and sediment sampling from across the Management Area will be performed on a six-monthly basis for an initial period of 3 years. This aims to capture potential variability in groundwater and surface water, if any, due to rainfall. The six-monthly schedule will aim to capture both the drier portion of the year (winter) and the wetter portion of the year (summer).

Following the development of a temporal dataset, it is considered that future ongoing monitoring will transition to an annual comprehensive event and a six-monthly event targeted at key locations on and off-Site.

Surface water sampling at the SMA during the DSI (AECOM, 2019) and HHERA (AECOM, 2021b) indicated surface water bodies and drainage lines are typically ephemeral and therefore may be unavailable for routine sampling events. Groundwater at the Base demonstrates limited variability in response to rainfall.

3.4 Monitoring Locations

3.4.1 Rationale for Groundwater Sample Locations

Groundwater monitoring will be undertaken on selected monitoring wells and residential bores.

The rationale for monitoring well selection for each area is summarised in Table 3-2 below. The proposed monitoring locations are presented on Figure 2A and 2B (Appendix A). It is noted that the locations are preliminary and will be subject to modification based on accessibility.

Table 3-2 Rationale for Groundwater Monitoring

Area	Rationale
On-Site	• Continue to monitor wells to develop temporal datasets to assist with better understanding of temporal patterns in PFAS concentrations • Provide early warning of PFAS concentrations migrating from the site boundary to the offsite Management Area • Assess if groundwater PFAS concentrations within and downgradient of the source areas change in response to management measures over time • Assess if background conditions change over time.
Northern boundary of SMA and off-site to the north	• Sentinel wells along northern boundary which will provide early warning of PFAS concentrations migrating from the SMA boundary into the offsite Management Area • Monitor groundwater wells on transects parallel and perpendicular to the SMA and off-site plume, to understand SMA contributions to the off-site plume, if any (refer to plume interpretation on Figure 5 in Appendix A) • Monitor potential changes in PFAS concentrations within the offsite plume and at identified plume margins • Continue to monitor wells to develop temporal datasets to assist with better understanding of temporal patterns in PFAS concentrations.
West and north west of the SMA	• Provide early warning of PFAS concentrations migrating from the SMA boundary to the offsite Management Area • Continue to monitor wells to develop temporal datasets to assist with better understanding of temporal patterns in PFAS concentrations.
East and north east of the SMA	• Monitor groundwater wells on transects parallel and perpendicular to the SMA and off-site plume, to confirm that the SMA is not contributing to off-site PFAS migration via groundwater • Continue to monitor wells to develop temporal datasets to assist with better understanding of temporal patterns in PFAS concentrations related to non-Base sources.

Off-site monitoring locations will require the agreement of the landholder/leaseholder. A stakeholder engagement plan will be prepared to manage this process.

3.4.2 Groundwater Sampling Method, Schedule and Locations

The groundwater sampling methodology will be in accordance with Section 18.0 of the NEMP (HEPA, 2020). The methodology and schedule are presented in Table 3-3 and locations are presented in Table 3-4.

Table 3-3 Groundwater Sampling Methodology and Schedule

Item	Details
Groundwater gauging	The depth to groundwater will be measured in each monitoring well prior to collection of groundwater samples. A comprehensive gauging round of all locations will be conducted prior to groundwater sampling to enable groundwater contours to be developed. The depth to groundwater will also be measured at the time of sampling at each location.
Sample Collection Methodology	**Groundwater Monitoring Wells** Groundwater samples will be collected from monitoring wells using no purge methodology using Hydrasleeves which will be installed within the screened interval of the wells. **Residential Bores** Bore water samples will be collected by placing the laboratory provided sample bottle beneath the tap outlet and the tap slowly opened to collect the “first flush” of water or by low flow groundwater sampling methodology using a peristaltic pump and micro purge pump. Bore construction details will be obtained for the private bores, where available, from the stakeholder. Additionally, permission will be requested from the stakeholder to access the bore to survey bore top of casing to enable accurate measurement of bore depth and standing water level. It is likely that bore connections will need to be removed to measure bore and groundwater depth.
QA/QC Samples to be Collected	Field QA/QC samples are to include intra-laboratory duplicate and inter-laboratory duplicate samples (i.e. splits) and rinsate samples. Duplicate samples are to be collected at a minimum frequency of 1 in ten primary samples. Rinsate samples are to be collected at a rate of one sample per fieldwork day or at least one rinsate sample per ten primary samples (whichever rate is lower) by pouring laboratory supplied deionised water over the decontaminated sampling equipment.
Field Parameters	Temperature, electrical conductivity (EC), dissolved oxygen (DO), oxidation-reduction potential (ORP), pH and observations of water quality will be recorded for all samples.
Sample Analysis	The standard PFAS suite for Defence PFAS investigations and management (refer to Appendix C).
Sampling Schedule	The monitoring will include monitoring over a period of three years comprising: • Annual monitoring of well locations GW04S, GW04D and GW05S at the northern Cantonment boundary • 6 monthly monitoring of well locations GW02S, GW02D, GW03S and GW03D at the northern Cantonment boundary for the first year. If results are comparable to those reported at these locations in the DSI and DSI addendum, the monitoring frequency may revert to an annual frequency. • Annual monitoring of Off Site well locations near the northern Cantonment boundary • Biennial (every other year) monitoring events of 12 groundwater well locations at PFAS source areas including the DNSDC Compound, Former Fire Station, Helicopter Landing Ground and Dochra Airfield Refer to Table 3-4 below.

Table 3-4 Groundwater Sample Locations

Area	Description	Sampling Locations	Number of wells/ bores	Total
On Site	Northern Cantonment Boundary	GW02S^, GW02D^, GW03S^, GW03D^, GW04S, GW04D, GW05S	7	19 Locations
	DNSDC Compound	CNN0039_GW01, CNN0039_GW02, CNN0039_GW03, CNN0039_GW05	4	
	Former Fire Station	CNN0018_GW02, CNN0018_GW03, CNN0018_GW08, CNN0230_GW01	4	
	Helicopter Landing Ground (HLG)	HLG_GW03	1	
	Dochra Airfield	NSW1164_MW01D, NSW1164_MW03S, NSW1164_MW03D	3	
Off Site	North of Site	GW06, GW08S, MW09S, MW09D, MW10S, MW10D, RESI_GW011*	7	12 Locations
	North west of Site	GW09S	1	
	North East of Site	GW07, RESI_GW13*, GW10S, GW12	4	

Note: * This location is a residential bore

All off-site groundwater monitoring wells are located on private property and will require the agreement of the landholder/leaseholder. A stakeholder engagement plan will be prepared to manage this process.

3.4.3 Rationale for Surface Water Sample Locations

The surface water monitoring locations have been selected to build on and maintain consistency with the monitoring completed during the DSI (AECOM, 2019). Additionally, as discussed in Section 2.3, surface water is the main migration pathway and as such is a key focus for the OMP. Many of the locations have been targeted to strategic areas of drainage catchments and have been previously sampled several times. Continued monitoring will provide additional data to assess temporal variability. The locations to be monitored on a six-monthly basis are provided in Table 3-6 below and are presented on Figure 3 in Appendix A.

Doughboy Hollow Creek catchment is proposed to be monitored at several on-site and offsite locations. An unnamed tributary of Doughboy Hollow Creek that runs through the central portion of the Cantonment (sub-catchment A) is proposed to be monitored at existing locations SW003, SW032, SMA13 and SMA8 which are positioned downstream of the identified Cantonment source areas. Additional monitoring is proposed for Doughboy Hollow Creek at boundary locations SW040, SMA7 and RESI_SW035 to monitor PFAS that may be migrating off-site to Doughboy Hollow Creek in surface water via sub-catchments B and C. One monitoring location, SW555, is proposed at the north-eastern Cantonment boundary, west of Range Road, where an unnamed tributary of Doughboy Hollow Creek enters sub-catchment B and flows onto the Site. The location is proposed to monitor potential on-site migration of PFAS that were detected on private properties east of the Base during the HHRA.

Ongoing monitoring is proposed at the north-east portion of the STA and will be undertaken at SW004 (Mudies Creek) and SW005 (Emigrant Creek) to assess runoff from the Dochra Airfield. These locations adequately represent the concentration of PFAS entering the off-site environment from the STA.

Monitoring is proposed at off-site locations (pending landowner consent) RESI_SW035 and RESI_SW036 to monitor PFAS concentrations in surface water downstream of the SMA. It is noted the water at these locations is thought to soak away to the alluvial sediments of Doughboy Hollow, upstream of the Hunter River flood plain (Whittingham).

Additional off-site monitoring is proposed in the vicinity of the Singleton STP and within the Hunter River floodplains at Whittingham at locations SW553, SW554, RESI_SW042 and RESI_SW041. Monitoring at these locations is proposed to understand off-site PFAS contributions, from the STP, to surface water courses in Doughboy Hollow, and eventually the Hunter River and monitor for any temporal changes.

3.4.4 Surface Water Sampling Method, Schedule and Locations

Table 3-5 provides the surface water sampling methodology and schedule and Table 3-6 details the surface water locations.

Table 3-5 Surface Water Sampling Methodology and Schedule

Item	Details
Sample Collection Methodology	Samples to be collected from immediately below the water surface to minimise collection of sediment or floating materials in the samples. At each location, a new, laboratory supplied container should be lowered into the water with the cap immediately applied once the container is full.
QA/QC Samples to be Collected	Field QA/QC samples are to include intra-laboratory duplicate and inter-laboratory duplicate samples (i.e. splits) and rinsate samples. Duplicate samples are to be collected at a minimum frequency of 1 in ten primary samples. Rinsate samples are to be collected at a rate of one sample per fieldwork day or at least one rinsate sample per ten primary samples (whichever rate is lower) by pouring laboratory supplied deionised water over the decontaminated sampling equipment.
Field Parameters	Temperature, EC, DO, ORP, pH and observations of water quality will be recorded for all samples.
Sample Analysis	PFAS extended suite using the standard levels of detection.
Sampling Schedule	The monitoring will include 6 monthly monitoring events at the selected 21 locations over the course of the OMP. The 6 monthly monitoring events will be scheduled to capture the wetter portion of the year (spring-summer) and drier portion of the year (autumn-winter).

Table 3-6 Surface Water Sampling Locations

Area	Description	Sampling Locations	Number of Locations	Total
On Site	Northern Cantonment (Sub-catchment A)	SW002, **SMA8**, SW003, SW032, SMA13	5	13 Locations
	Northern Cantonment boundary	SW115	1	
	Central Cantonment (Sub-catchment B)	SMA7, SW555	2	
	Southern Cantonment (Sub-catchment C)	SW040, SW113, SW114	3	
	Dochra Airfield	SW004, **SW005**	2	
Off Site	West of Site (Doughboy Hollow Creek)	RESI_SW035*	1	8 locations
	North of Site (Doughboy Hollow Creek Catchment)	RESI_SW036*, OTH006, SW553, SW554, RESI_SW042*, RESI_SW041*	6	
	East of Site (Doughboy Hollow Creek Catchment)	RESI_SW039*	1	
	South of Site	Nil	0	

Notes: Locations in **bold** are proposed for monthly sampling for a minimum of 12 months.
Locations denoted by * are on residential properties.

3.4.6 Rationale for Sediment Sampling

The sediment sample locations have been selected to be co-located with surface water sample locations and to maintain consistency with the monitoring completed during the DSI. Many of the locations have been previously sampled several times, and continued monitoring will provide additional data to assess temporal variability. The locations to be monitored on a six-monthly basis are provided in Table 3-8 below and are presented on Figure 4 in Appendix A.

3.4.7 Sediment Sampling Method, Schedule and Locations

Table 3-7 below provides the sediment sampling methodology and schedule and Table 3-9 summarises the sediment sampling locations.

Table 3-7 Sediment Sampling Methodology and Schedule

Item	Details
Sample Collection Methodology	Samples representative of potentially deposited sediments to be collected from within the water body if possible. Sediment samples will be collected using a hand auger from the base of the drain (where it is safe to do so) or using a Dormer Piston Sediment Sampler where access is restricted. At each location, a new laboratory supplied container should be used for each sample.
QA/QC Samples to be Collected	Field QA/QC samples are to include intra-laboratory and inter-laboratory duplicate samples (i.e. splits) and rinsate samples. Duplicate samples are to be collected at a minimum frequency of 1 in ten primary samples. Rinsate samples will be collected at a rate of one sample per fieldwork day or at least one rinsate sample per ten primary samples (whichever rate is lower) by pouring laboratory supplied deionised water over decontaminated sampling equipment.
Sample Analysis	PFAS extended suite using the standard levels of detection
Sampling Schedule	The monitoring will include bi-annual monitoring events at all 20 locations.

Table 3-8 Sediment Sample Locations

Area	Description	Sampling Locations	Number of Locations	Total
On Site	Northern Cantonment (Sub-catchment A)	SD002, SMA8_SD, SD003, SD032, SMA13_D	5	13 Locations
	Northern Cantonment boundary	SD115	1	
	Central Cantonment (Sub-catchment B)	SMA7_SD, SD555	2	
	Southern Cantonment (Sub-catchment C)	SD040, SD113, SD114	3	
	Dochra Airfield	SD004, SD005	2	
Off Site	West of Site	RESI_SD035	1	7 locations
	North of Site	RESI_SD013, SD539, SD540, RESI_SD042, RESI_SD041	5	
	East of Site	RESI_SD039	1	
	South of Site	Nil	0	

3.5 Sample Analysis

Samples should be analysed for PFAS in accordance with the PFAS Suite for Defence PFAS Investigation and Management as provided in Appendix C.

The laboratory is required to use NATA accredited methods based on NEPM, US EPA, Table B 15 of the US Department of Defence/Department of Energy (US DOD/DoE) and American Society for Testing and Materials (ASTM) methods as appropriate.

Quality control and quality assurances processes will be outlined within the SAQP.

All media sampled shall be analysed for the extended PFAS suite as outlined in Table 3-9 below.

Table 3-9 Sample Analytical Suite for PFAS

PFAS Group	Compound	CAS No.
Perfluoroalkyl Sulfonic Acids	Perfluorobutane sulfonic acid (PFBS)	375-73-5
	Perfluoropentane sulfonic acid (PFPeS)	2706-91-4
	Perfluorohexane sulfonic acid (PFHxS)	355-46-4
	Perfluoroheptane sulfonic acid (PFHpS)	375-92-8
	Perfluorooctane sulfonic acid (PFOS)	1763-23-1
	Perfluorodecane sulfonic acid (PFDS)	335-77-3
Perfluoroalkyl Carboxylic Acids	Perfluorobutanoic acid (PFBA)	375-22-4
	Perfluoropentanoic acid (PFPeA)	2706-90-3
	Perfluorohexanoic acid (PFHxA)	307-24-4
	Perfluoroheptanoic acid (PFHpA)	375-85-9
	Perfluorooctanoic acid (PFOA)	335-67-1
	Perfluorononanoic acid (PFNA)	375-95-1
	Perfluorodecanoic acid (PFDA)	335-76-2
	Perfluoroundecanoic acid (PFUnDA)	2058-94-8
	Perfluorododecanoic acid (PFDoDA)	307-55-1
	Perfluorotridecanoic acid (PFTrDA)	72629-94-8
	Perfluorotetradecanoic acid (PFTeDA)	376-06-7
Perfluoroalkyl Sulfonamides	Perfluorooctane sulphonamide (FOSA)	754-94-6
	N-Methyl perfluorooctane sulfonamide (MeFOSA)	31506-32-8
	N-Ethyl perfluorooctane sulfonamide (EtFOSA)	4151-50-2
	N-Methyl perfluorooctane sulfonamidoethanol (MeFOSE)	2448-09-7
	N-Ethyl perfluorooctane sulfonamidoethanol (EtFOSE)	1691-99-2
	N-Methyl perfluorooctane sulfonamidoacetic acid (MeFOSAA)	2355-31-9
	N-Ethyl perfluorooctane sulfonamidoacetic acid (EtFOSAA)	2991-50-6
(n:2) Fluorotelomer Sulfonic Acids	4:2 Fluorotelomer sulfonic acid (4:2 FTS)	757124-72-4
	6:2 Fluorotelomer sulfonic acid (6:2 FTS)	27619-97-2
	8:2 Fluorotelomer sulfonic acid (8:2 FTS)	39108-34-4
	10:2 Fluorotelomer sulfonic acid (10:2 FTS)	120226-60-0

The current standard laboratory limits of reporting (LOR) are described in Table 3-10 below.

Table 3-10 Laboratory Limits of Reporting

Sample Media	Parameter	Technique/Method Reference	LOR*
Groundwater and Surface Water	Extended PFAS Suite	LC/MS-MS	0.002 – 0.1 µg/L
Sediment	Extended PFAS Suite	LC/MS-MS	0.0002 – 0.001 mg/kg

LC/MS-MS = Liquid chromatography–mass spectrometry, GC = Gas chromatography
*LOR for Australian Laboratory Services (ALS)

4 REPORTING REQUIREMENTS

4.1 Guidance Documents

The PFAS NEMP (HEPA, 2020) provides the guiding framework for the management of PFAS. For further information, see: http://www.epa.vic.gov.au/PFAS_NMP.

The NEMP (HEPA, 2020) aims to provide governments with a consistent, practical, risk-based framework for the environmental regulation of PFAS-contaminated materials and sites. The NEMP has been developed collaboratively by the Heads of EPAs Australia and New Zealand and the Commonwealth Department of Environment and Energy (DoEE) and has been endorsed by the Commonwealth Government.

The PFAS Response Management Strategy and the requirements of the OMP template and guidance conform to the NEMP (HEPA, 2020).

4.2 PFAS Screening Criteria

The screening criteria for groundwater and surface water are summarised below.

Table 4-1 Screening criteria for surface water and groundwater (µg/L)

Pathway	Compound	Criteria	Comment / Reference
Drinking water - groundwater	PFOS + PFHxS	0.07 µg/L	The values presented in the NEMP (2020) are from the Department of Health (DoH) (2017), which published final health-based guidance values for PFAS for use in site investigations in Australia. DoH utilised the Tolerable Daily Intake (TDI) for PFOS and PFOA from Food Standards Australia New Zealand (FSANZ) [2017] and the methodology described in Chapter 6.3.3 of the National Health and Medical Research Council's (NHMRC) of the Australian Drinking Water Guidelines (ADWG, 2016) to determine drinking water values. As a precaution, the Australian Government Department of Health has advised that the PFOS TDI should also apply to PFHxS, meaning the level of PFHxS exposure should be added to the level of PFOS exposure. The combined level should then be compared to the TDI for PFOS. All groundwater and surface water results will be compared to these criteria.
	PFOA	0.56 µg/L	
Recreational use – surface water	PFOS + PFHxS	2 µg/L	The values presented in the NEMP (HEPA, 2020) are typically consistent with those provided in the NEMP (2018) which were in turn adopted from the DoH (2017), which published health-based guidance values for PFAS for use in site investigations in Australia. As with the drinking water values, the DoH utilised the TDI for PFOS and PFOA from FSANZ (2017) and 'the methodology described in Chapter 6.3.3 of the NHMRC of the ADWG (2016) to determine recreational water quality values' (DoH, 2017). Notwithstanding, the recreational water quality values provided in NEMP (HEPA, 2020) have been updated from the values published in the NEMP (2018) and are based on revised numbers derived by NHMRC in 2019. The revised numbers are based on changes in the assumption for the frequency and likelihood of exposure during recreational activities. All groundwater and surface water results will be compared to these criteria.
	PFOA	10 µg/L	

Table 4-2 PFAS criteria summary: Ecological

Media	Pathway	Chemical	Criteria	Comment/Reference
Water	Freshwater	PFOS	0.00023 µg/L	HEPA (2020) NEMP 99% species protection
		PFOA	19 µg/L	HEPA (2020) NEMP 99% species protection

Note: HEPA (2020) notes that the 99% species protection level for PFOS is close to the level of detection. Agencies may wish to apply a 'detect' threshold in such circumstances rather than a quantified measurement.

4.3 Trigger levels and Responses

Table 4-3 below sets out initial trigger levels and responses. These will be reviewed with each review of the OMP.

Table 4-3 PFAS Trigger Levels and Responses

Trigger	Response
First time detect (i.e. previously non-detect) of PFAS above laboratory LOR in surface water or groundwater	• Request the analytical laboratory to reanalyse the sample to verify detection • If initial sample verified by laboratory, resample location within one month and verify detection • If detection verified in second sample, review CSM and potential risks to human health and environment • Notify NSW EPA and other relevant agencies • Consider increasing the monitoring frequency at the location • Implement additional investigations or management actions as required.
First time exceedance of the drinking water guideline values in groundwater or the recreational water guideline values in surface water	• Request the analytical laboratory to reanalyse the sample to verify detection • If initial sample verified by laboratory, resample location within one month and verify detection • Calculate rolling average over a three year period for sample results from the same location and compare with the appropriate guideline value • If rolling average exceeds appropriate guideline value, review CSM and potential risks to human health and environment • Notify NSW EPA and other relevant agencies • Consider increasing the monitoring frequency at the location • Implement additional investigations or management actions as required.
Increasing PFAS trends	Further assessment of the data to determine if additional management actions are required. If increasing PFAS levels in surface water samples are identified then this may indicate increased risks to receptors in the Management Area.
Decreasing PFAS trends	Review monitoring frequency and / or need for ongoing monitoring at this location as part of annual OMP review.

Trigger	Response
Increasing PFAS trends in sediment	• Review sediment results alongside surface water results • Review data against the conceptual site model • Review surface water levels from the sampling, and consider if additional sampling during a rain event is required • Consider increasing the monitoring frequency at the location(s) of interest • Implement additional investigations or management actions as required

4.4 Reporting

After each monitoring event, the information and laboratory data collected as part of the works will be documented and reported to Defence.

The data set will be reviewed at the end of each 12-month monitoring period. An interpretative report is to be drafted, including recommendations for any potential changes in the location and frequency of sampling, with consideration to the points contained in Section 5.2. The interpretive report will be prepared with reference to OMP Annual Interpretive Reporting Guidance document (Defence, 2020)

4.4.1 Interpretative Report

The annual report should include, as a minimum:

- field works completed (including scope unable to be achieved, such as monitoring well access
- description of the sampling methodology
- compliance with the requirements of the SAQP and meeting stated objectives of the OMP
- findings from well gauging including any changes with the monitoring well network including access and damage issues
- relevant figures depicting sampling locations and site-specific hydrogeological features;
- laboratory results and analysis including comparison with relevant screening criteria identified in section 4.2
- assessment and commentary on appropriate QA/QC procedures
- data interpretation including trends in groundwater concentration, gradient and flow directions
- assessment of statistically based trends that may inform decision making (refer to section 5.3)
- provision, at a minimum, of groundwater sampling forms, laboratory analytical certifications and calibration certificates.

4.4.2 Stakeholder Engagement

Analytical results from each monitoring round will be provided to the NSW EPA, including the annual interpretative report.

Where off-site residential sampling is proposed, a separate letter will be produced to provide to the resident with the analytical results of the monitoring event and assessment against relevant guideline values.

5 REVIEW AND UPDATE

This section of the OMP details uncertainties in investigation, monitoring and management that may require consideration of contingency measures and/or reassessment of risk with changes in conditions including necessity for additional investigations.

5.1 Monitoring of Management Measures

In general terms, the OMP will cover:

- the primary implementation period of the PMAP
- the extended implementation period to the extent required by specific characteristics of the Management Area and the behaviour of the plume, measured against specific data trends.

Each Remedial Action Plan developed for identified management options within the PMAP will require an individual monitoring plan with appropriate objective and success measures as relevant to monitoring of that action.

5.2 Triggers for OMP Review

Updates to the OMP may be required for several reasons:

1. Data on changes in the distribution, concentration, transport (pathways and flow rates) and transformation of the contaminants and assessment against appropriate guideline values provides an evidence base for targeted and effective risk management of PFAS contamination to protect human health and environmental receptors currently impacted by PFAS.
2. Changes in our understanding of these risks, triggered by this data assessment may inform:

- an early warning that additional management of PFAS contamination may be warranted in areas not currently affected by PFAS
- changes detected through the implementation of the OMP may inform a number of risk-management decisions including:
    - additional investigations
    - re-assessment of one or more remediation or containment actions
    - additional remediation or containment actions
    - changing risk management actions at receptor level (e.g. provision or cessation of alternate drinking water supplies).

An update to the OMP may also be triggered by policy changes or through stakeholder engagement activities including:

- changes to NSW EPA advice on types of exposure-minimisation behaviours (e.g., consumption of home produce or seafood)
- changes to State/Territory advice on boundaries of a designated management area and the management zones within
- changes or refinements to the monitoring network, frequency and parameters
- feedback and information received as a result of on-going community consultation
- any significant changes of land use which may occur in the area within the Management Area or adjoining land
- changes to Defence’s strategic approach to managing PFAS contamination.

5.3 Monitoring Potential Future Risks

Findings from the ongoing monitoring will be used to evaluate whether changes have occurred to the risk posed by PFAS contaminated groundwater and surface water across the Management Area. This may be achieved through:

- comparison of our current understanding of the nature and extent of the plume as presented in the DSI (AECOM, 2019)
- this may trigger evaluation of the monitoring program and an updated scope of works
- include relevant site-specific considerations, such as potential changes in known concentrations within receiving environments or ecological receptors.

5.4 Document Review Frequency

The OMP will be reviewed regularly. The review frequency will be based on site specific characteristics and the existing data trend available. The review frequency may be revised during the implementation period as more data becomes available.

Based on the current understanding and existing data, this OMP should be implemented for an initial three-year period, and subsequently revised if the monitoring reports trigger this change.

5.5 Existing Knowledge

The document has been developed on the basis of existing knowledge, current government policy settings, and available scientific methodologies and technology at the time of publication. PFAS management is a field that is rapidly evolving.

Over the primary implementation period of the PFAS Management Area Plan, Defence will review and update (where necessary) the PMAP at intervals of 12 months to ensure that the document is current, and its recommendations are valid.

The OMP should be subsequently updated in light of the considerations outlined in Section 5 as well as reviews and updates to the PMAP to ensure the document is current and its recommendations valid.

6 REFERENCES

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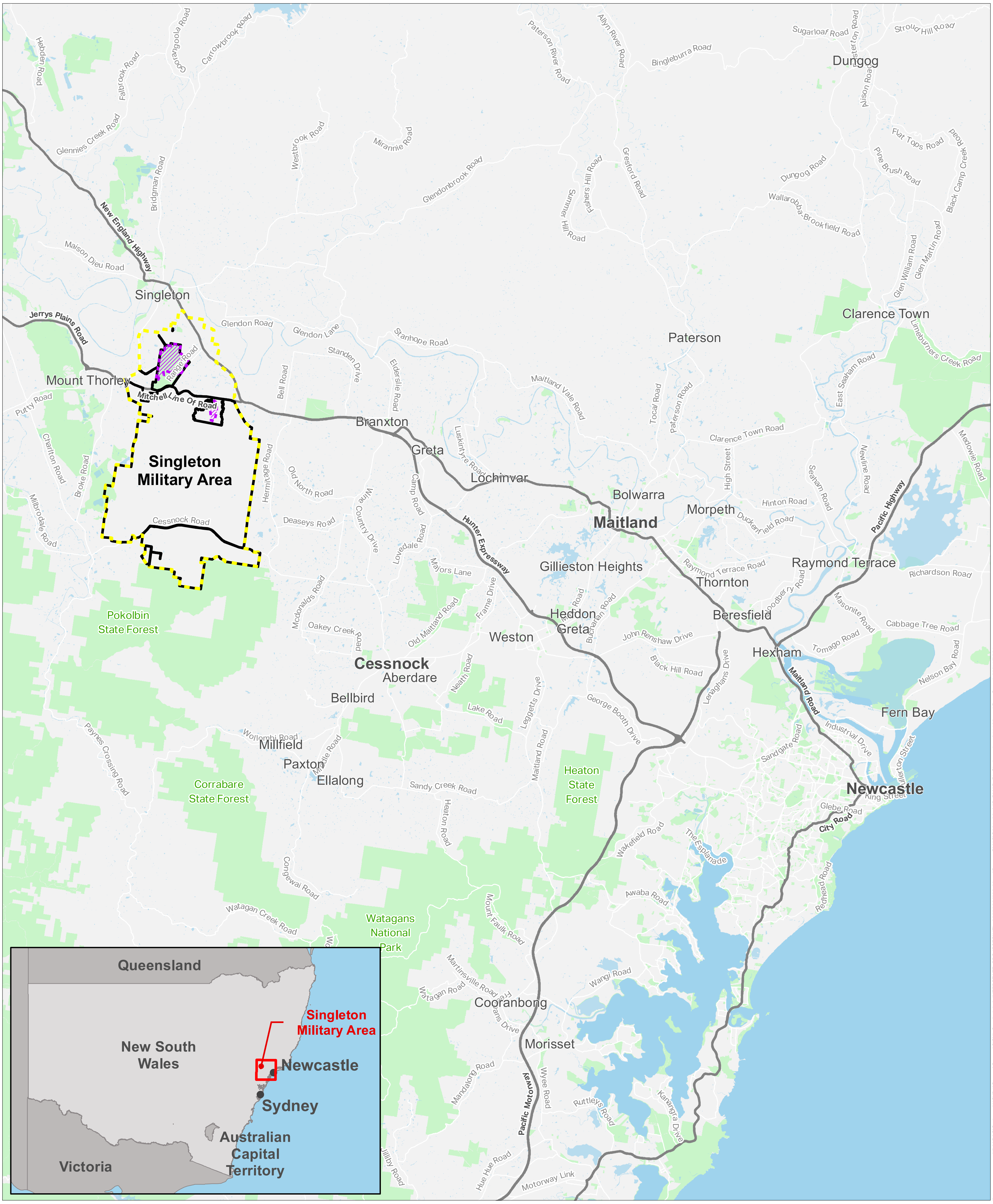
Standards Australia (AS 4482.1-2005) *Guide to the sampling and investigation of potentially contaminated soil. Part 1: Non-volatile and semi-volatile compounds*

APPENDIX A: Figures



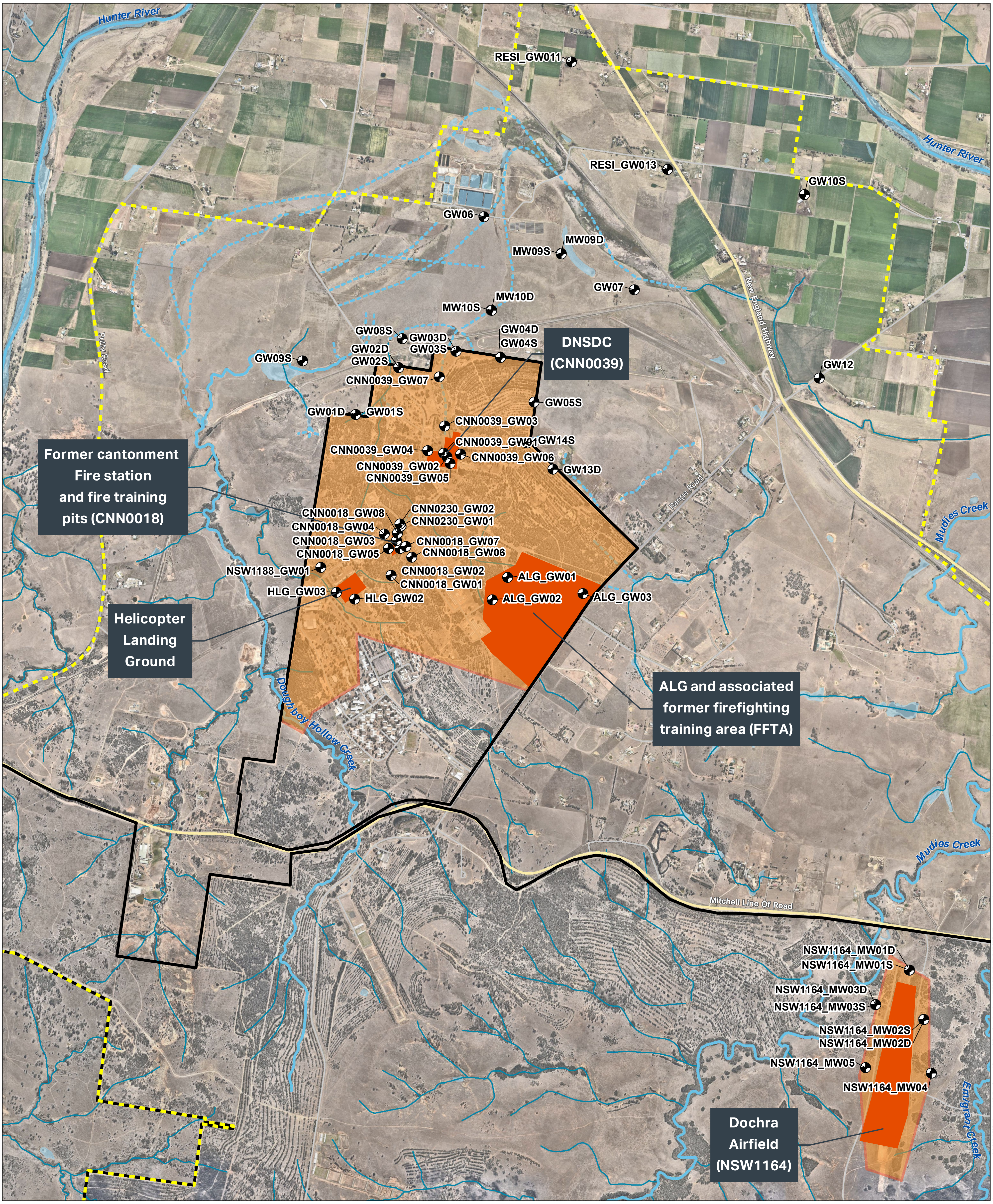
OMP - F1: SITE LOCATION

km
0 5 10

Legend

- Property boundary
- Former Investigation Area
- On-Site Management Area
- Highways
- Main Roads
- Waterbody
- Parks, Forests and Reserves

Source: © Department Finance, Services & Innovation (2018)



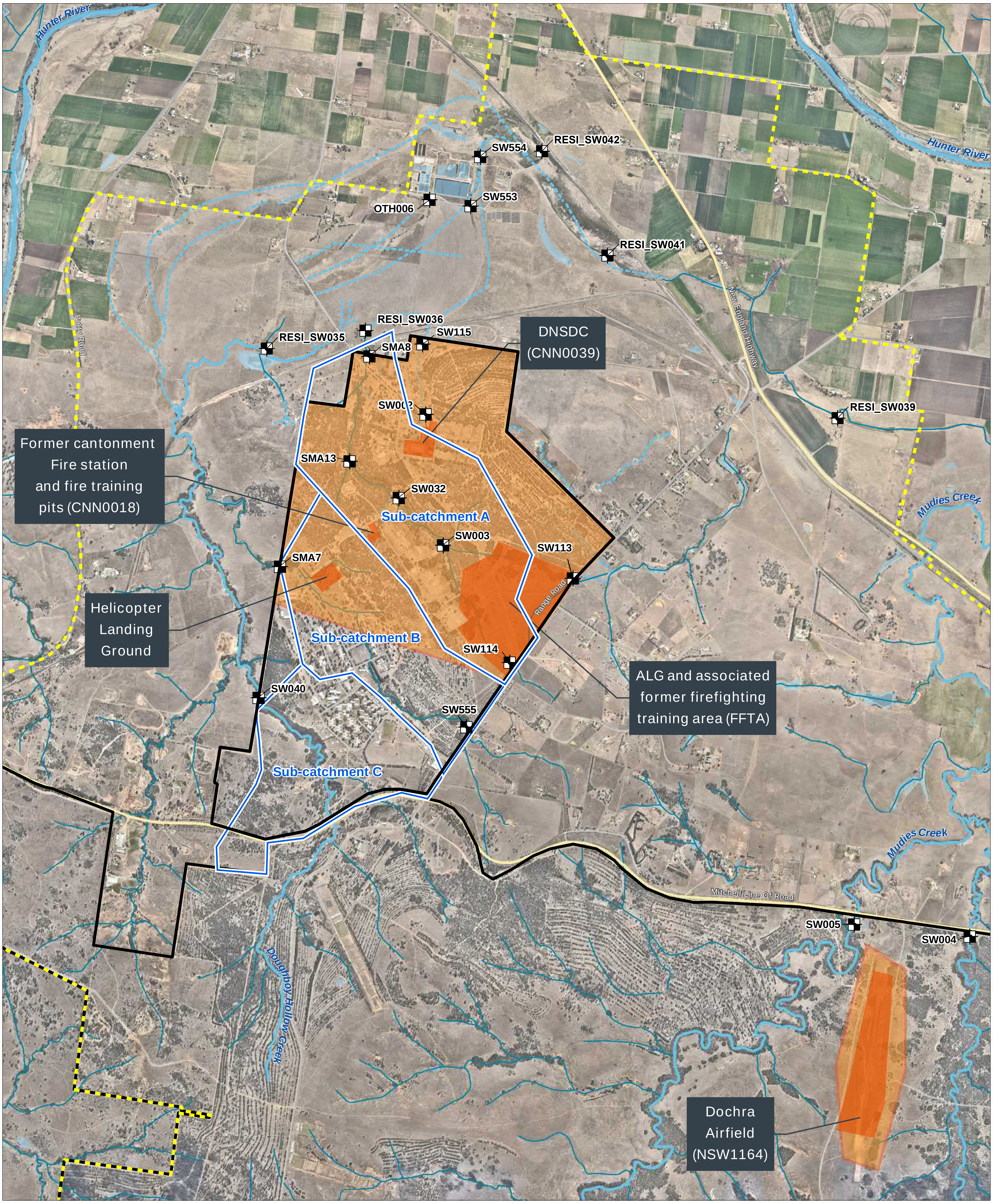
F2: GROUND WATER SAMPLE LOCATIONS

AECOM

N

0 0.45 0.9 km

- Property Boundary
- Former Investigation Area
- Targeted Source Areas
- On-Site Management Area
- Proposed groundwater sample location
- Highways
- Main Roads
- Local Roads
- Railway
- Waterbody
- State Forest



F3: SURFACE WATER SAMPLE LOCATIONS

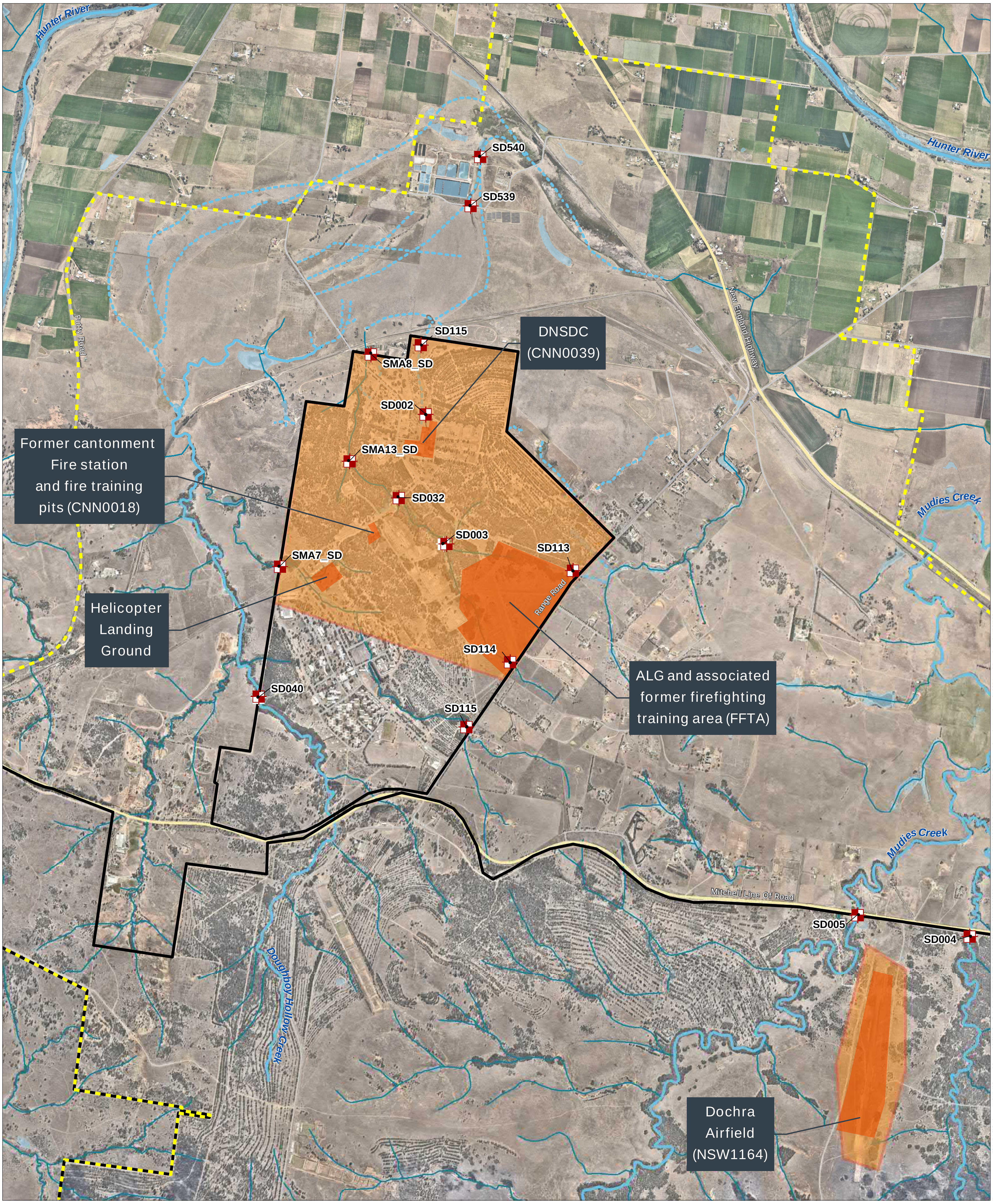
AECOM

km
0 0.45 0.9

- Property Boundary
- Former Investigation Area
- Targeted Source Areas
- On-Site Management
- Proposed surface water sample location
- Catchment Boundaries
- Highways
- Main Roads
- Local Roads
- Railway
- Waterbody
- State Forest

Source: © Department Finance, Services & Innovation (2018)
Imagery © Nearmap, 2018

Note: for privacy reasons, selected proposed monitoring locations have been omitted under advice from private property owners



F4: SEDIMENT SAMPLE LOCATIONS

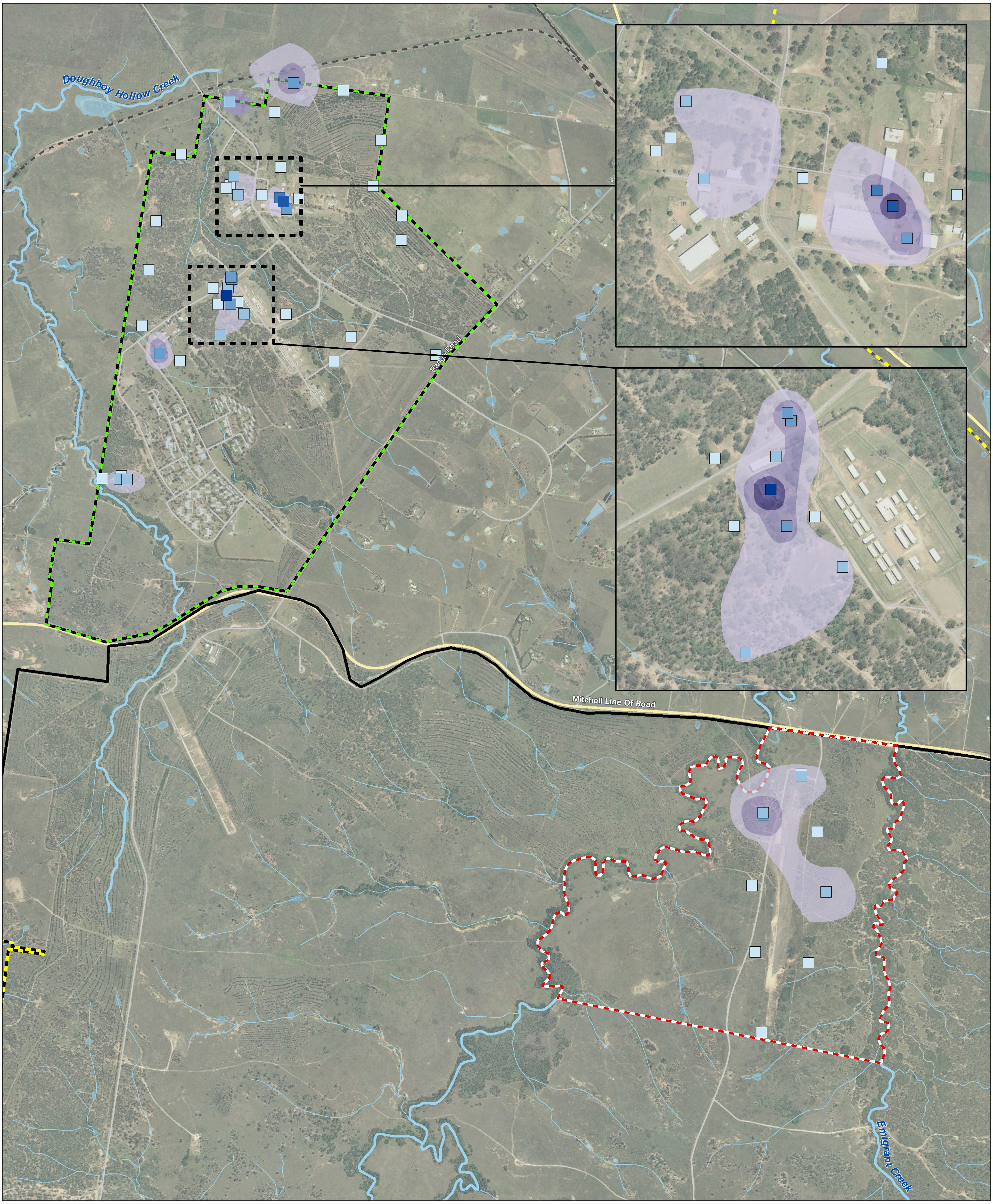
AECOM

km
0 0.45 0.9

- Property Boundary
- Former Investigation Area
- Targeted Source Areas
- On-Site Management Area
- Proposed sediment sample location
- Highways
- Main Roads
- Local Roads
- Railway
- Waterbody
- State Forest

Source: © Department Finance, Services & Innovation (2018)
Imagery © Nearmap, 2018

Note: for privacy reasons, selected proposed monitoring locations have been omitted under advice from private property owners



F5A: INTERPRETED EXTENT OF GROUNDWATER IMPACT PFOS + PFHxS SINGLETON MILITARY AREA

AECOM

0 0.4 0.8 km

The greatest reported PFOS+PFHxS concentration from the PSI, DSI and DSI addendum is presented at each sampling point. This figure has been compiled to provide a visual representation of contoured PFOS+PFHxS concentrations in sampled monitoring wells and does not represent the full nature and extent of groundwater impacts in the area, nor does it represent inferred aquifer conditions. The shading provided on this figure represents the area over which PFOS+PFHxS has been detected at various concentration intervals (refer to legend) in groundwater. This figure is not intended to be used for the purpose of understanding the full extent of bore water and/or aquifer impacts, but provides a visual indication of potential exposure point concentrations. This figure should be used for preliminary indicative purposes only and will be subject to change as additional data is collected.
Monitoring wells installed as part of the DSi addendum are included in this figure.

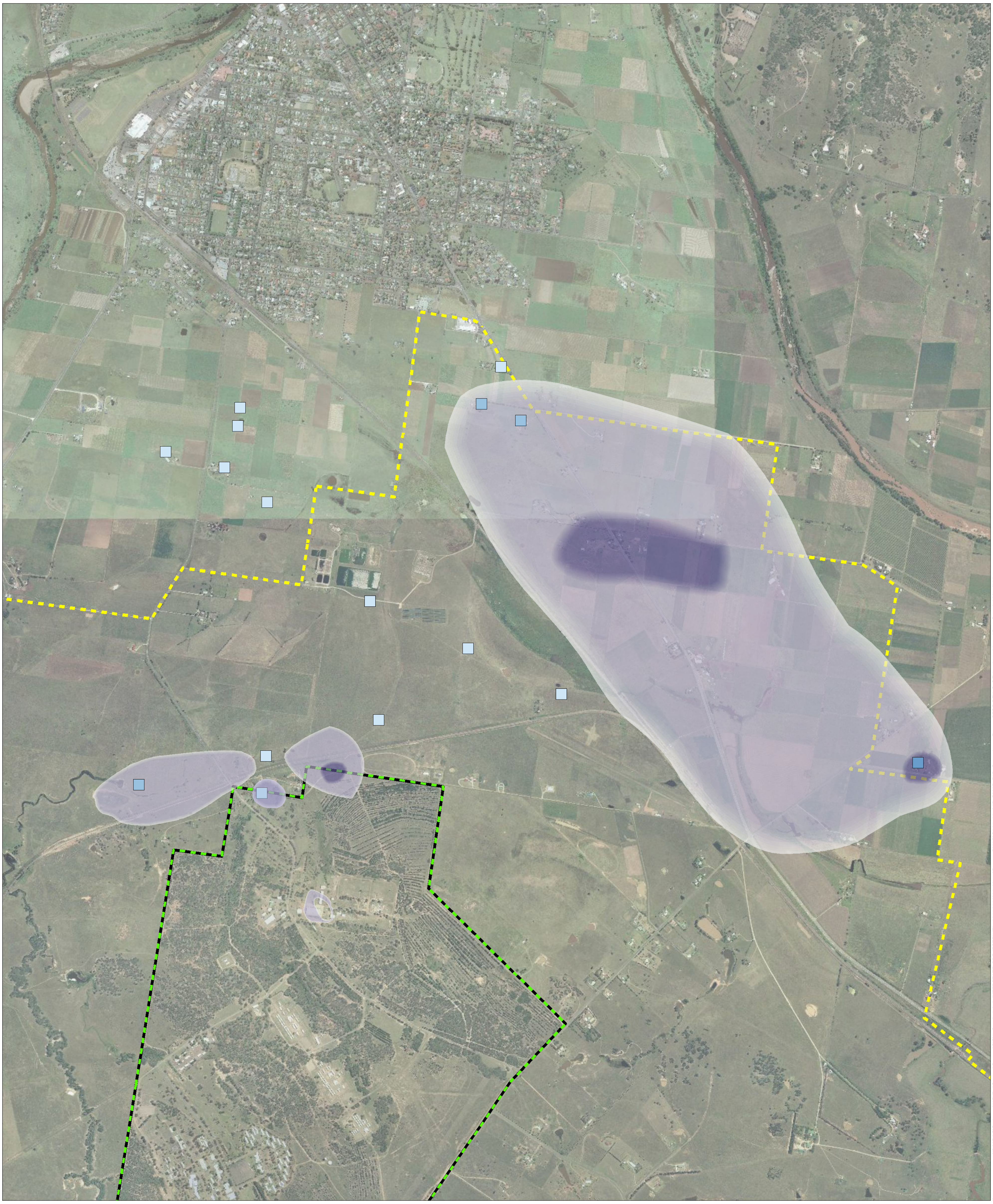
- Property Boundary
- Dochra Airfield Investigation Boundary
- Cantonment Boundary
- Former Investigation Area
- Waterbody
- Watercourses

Interpretted PFOS + PFHxS Concentration (µg/L)

- > 10
- > 0.07 - 10
- > LOR - 0.07

Groundwater - PFOS + PFHxS (ug/L)

- > 50
- > 10 - 50
- > 2 - 10
- > 0.07 - 2
- > LOR - 0.07
- < LOR



F5B:INTERPRETED EXTENT OF GROUNDWATER IMPACT PFOS + PFHxS
OFF-SITE INVESTIGATION AREA

0 0.35 0.7 km

The greatest reported PFOS+PFHxS concentration from the PSI, DSI and DSI addendum is presented at each sampling point. This figure has been compiled to provide a visual representation of contoured PFOS+PFHxS concentrations in sampled monitoring wells and does not represent the full nature and extent of groundwater impacts in the area, nor does it represent inferred aquifer conditions. The shading provided on this figure represents the area over which PFOS+PFHxS has been detected at various concentration intervals (refer to legend) in groundwater. This figure is not intended to be used for the purpose of understanding the full extent of bore water and/or aquifer impacts, but provides a visual indication of potential exposure point concentrations. This figure should be used for preliminary indicative purposes only and will be subject to change as additional data is collected.
Monitoring wells installed as part of the DSi addendum are included in this figure.

Groundwater - PFOS + PFHxS (ug/L)

PFOS + PFHxS

- > 0.07 - 2
- > LOR - 0.07
- < LOR
- Property Boundary
- Cantonment Boundary
- Investigation Area
- Waterbody

Interpretted PFOS + PFHxS Concentration (µg/L)

- > 10
- > 0.07 - 10
- > LOR - 0.07

Groundwater - PFOS + PFHxS (ug/L)

- > 50
- > 10 - 50
- > 2 - 10
- > 0.07 - 2
- > LOR - 0.07
- < LOR

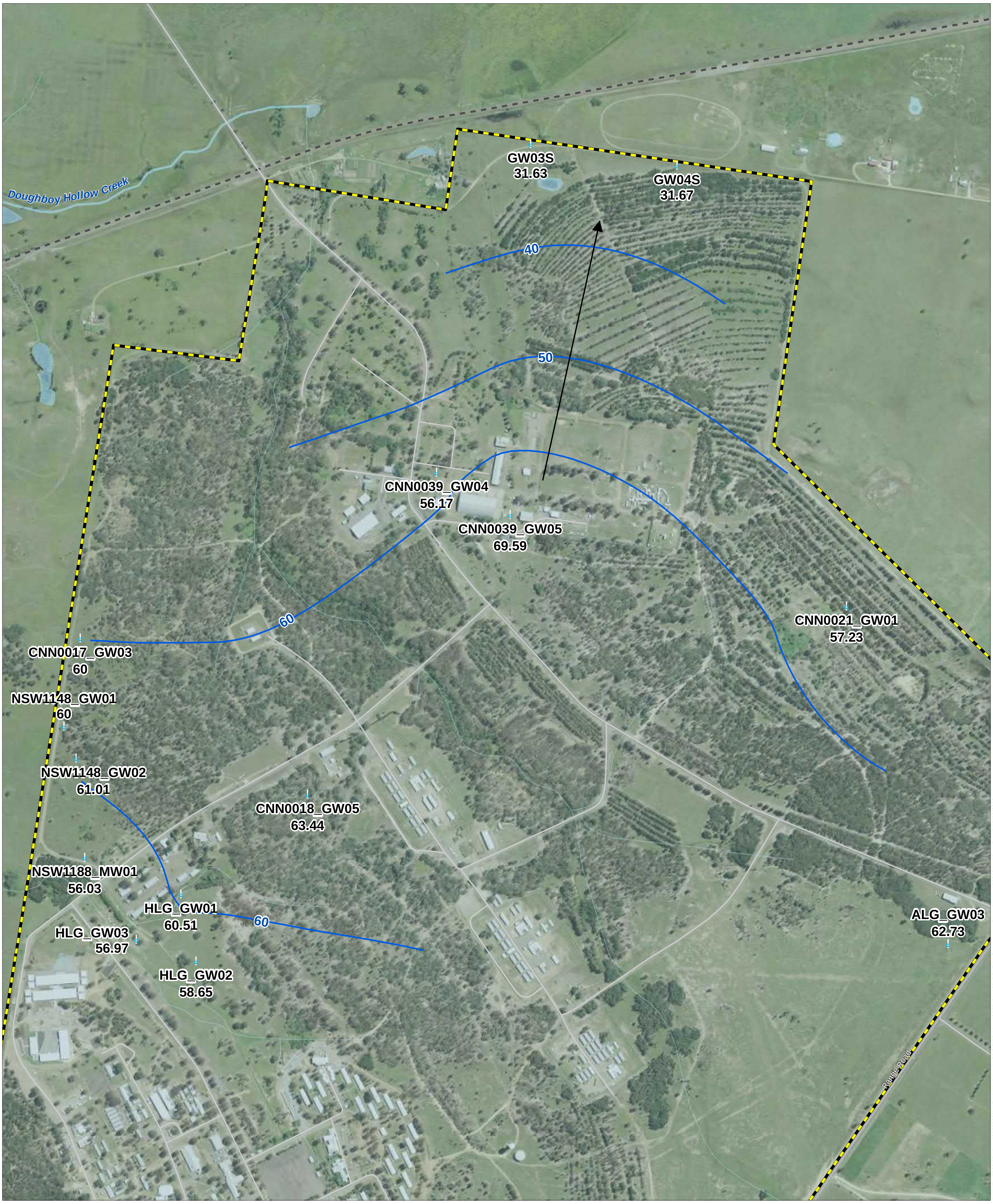


FIGURE 6A: INFERRED GROUNDWATER FLOW DIRECTION (WITHIN SHALE) CANTONMENT - SINGLETON MILITARY AREA

AECOM

N

0 0.15 0.3 km

Source: © Department Finance, Services & Innovation (2018)

- Cantonment Boundary
- Property Boundary
- Waterbody
- Watercourses
- Railway
- Main Roads
- Local Roads
- Groundwater Well
- 11 Groundwater Elevation (mAHD)
- Inferred Groundwater Flow Direction
- Groundwater Contours (mAHD)

FIGURE 6B: INFERRED GROUNDWATER FLOW DIRECTION (WITHIN SHALE) DOCHRA AIRFIELD - SINGLETON MILITARY AREA

AECOM

N

0 0.095 0.19 km

Source: © Department Finance, Services & Innovation (2018)

- gw_elevations2_SC_RangeShale... Events
- Dochra Airfield Investigation Boundary
- Property Boundary
- Waterbody
- Watercourses
- Local Roads
- Groundwater Well
- 11 Groundwater Elevation (mAHD)
- Inferred Groundwater Flow Direction
- Groundwater Contours (mAHD)

APPENDIX B: SAQP Guidance

The objective of the SAQP is to outline the monitoring locations, data quality assurance procedures and justify sampling methods and procedures to be used during the monitoring events based on the technologies available at the time of monitoring.

Some text below has been provided for consideration to allow for consistency across the Defence program when drafting site specific SAQPs.

Other standard information may be included within the development stage of the SAQP rather than within this OMP, such as decontamination procedures, sample identification, preservation, and appropriate record keeping.

The SAQP will be a stand-alone document that details, at a minimum, the following:

- Introduction including background and summary of previous investigations;
- Site setting and conceptual site model;
- Data Quality Objectives as detailed within the Ongoing Monitoring Plan, and a description of any inclusions or deviations from the objective or scope;
- Field work sampling methodology, equipment and laboratory analysis;
- Waste management;
- Quality Assurance/Quality Control procedures; and
- Fieldwork Documentation.

Laboratory Analysis

Within the SAQP, the primary contaminants of concern are defined as PFAS and referenced in Guidance Document E – Standard PFAS Analytical Suite for Detailed Site Investigations (Department of Defence, 2018a).

Other contaminants of potential concern are defined as those listed as non-PFAS compounds and are not considered as part of this investigation, unless determined necessary to supplement new and existing data.

Laboratory sampling analysis is to be conducted using NATA certified laboratories which will implement a quality control plan in accordance with NEPM (1999).

Sampling Methodology

Sampling and monitoring should be undertaken in accordance with the Heads of EPAs Australia and New Zealand (HEPA), 2018, PFAS National Environmental Management Plan and with requirements contained in AS5667.11:1998 Water Quality Sampling Part 11: Guidance on Sampling of Groundwaters and Schedule B2 of the ASC NEPM (2013).

Groundwater Sampling

Prior to sampling, groundwater wells are to be gauged with an interface water level probe to determine depth to water level below top of casing. The location and elevation of groundwater wells is to be recorded to inform our current understanding of groundwater flow direction.

Groundwater samples will be collected from each well with the method consistent with previous investigations to allow for comparison of data for trend analysis and evaluation, such as through either a low/high flow pump purging or via a hydrosleeve grab sampler.

Physical indicators such as the presence (and percentage) of suspended solids, colour, the presence/absence and nature of odours and the presence/absence of slicks or sheens on water sampled will be recorded on field sheets.

Surface Water Sampling

Surface water samples should be collected in accordance with PFAS NEMP (2020) guidelines.

Surface water samples should be collected from either mid-way through the water column or approximately 0.5 m below the surface (if possible), without disturbing the bottom of the surface water body. Samples should be collected without capturing any surface film.

Quality Control and Quality Assurance Processes

Both field and laboratory QA/QC processes should be undertaken in accordance with the most recent state or national guidance.

APPENDIX C: PFAS Analytical Suite

Australian Government
Department of Defence

Department of Defence

PFAS INVESTIGATION AND MANAGEMENT

GUIDANCE DOCUMENT E
STANDARD PFAS ANALYTICAL SUITE

6 April 2018

Document Version History

Document Reference	Revision	Date
AF29889468	1	10 July 2017
AF32594670	2	21 March 2018
AF32594670	3	6 April 2018

The following is the standard PFAS Suite for Defence PFAS investigations and management;

Group	Acronym	Chemical Compound	CAS No
Perfluoroalkane Sulfonic Acids	PFBS	Perfluorobutane sulfonic acid	375-73-5
	PFPeS	Perfluoropentane sulfonic acid	2706-91-4
	PFHxS	Perfluorohexane sulfonic acid	355-46-4
	PFHpS	Perfluoroheptane sulfonic acid	375-92-8
	PFOS	Perfluorooctane sulfonic acid	1763-23-1
	PFDS	Perfluorodecane sulfonic acid	335-77-3
Perfluoroalkane Carboxylic Acids	PFBA	Perfluorobutanoic acid	375-22-4
	PFPeA	Perfluoropentanoic acid	2706-90-3
	PFHxA	Perfluorohexanoic acid	307-24-4
	(PFHpA)	Perfluoroheptanoic acid	375-85-9
	PFOA	Perfluorooctanoic acid	335-67-1
	PFNA	Perfluorononanoic acid	375-95-1
	PFDA	Perfluorodecanoic acid	335-76-2
	PFUnDA	Perfluoroundecanoic acid	2058-94-8
	PFDoDA	Perfluorododecanoic acid	307-55-1
	PFTrDA	Perfluorotridecanoic acid	72629-94-8
	PFTeDA	Perfluorotetradecanoic acid	376-06-7
Perfluoroalkyl Sulfonamides	FOSA	Perfluorooctane sulfonamide	754-91-6
	MeFOSA	N-Methyl perfluorooctane sulfonamide	31506-32-8
	EtFOSA	N-Ethyl perfluorooctane sulfonamide	4151-50-2
	MeFOSE	N-methyl perfluorooctane sulfonamidoethanol	24448-09-7
	EtFOSE	N-Ethyl perfluorooctane sulfonamidoethanol	1691-99-2
	MeFOSAA	N-methyl perfluorooctane sulfonamidoacetic acid	2355-31-9
	EtFOSAA	N-ethyl perfluorooctane sulfonamidoacetic acid	2991-50-6
(n:2) Fluorotelomer Sulfonic Acids	4:2 FTS	4:2 Fluorotelomer sulfonic acid	757124-72-4
	6:2 FTS	6:2 Fluorotelomer sulfonic acid	27619-97-2
	8:2 FTS	8:2 Fluorotelomer sulfonic acid	39108-34-4
	10:2 FTS	10:2 Fluorotelomer sulfonic acid	120226-60-0

The standard PFAS Suite is based on consideration of;

- US EPA Method 537 (September 2009). Determination of Selected Perfluorinated Alkyl Acids in Drinking Water by Solid Phase Extraction and Liquid Chromatography/Tandem Mass Spectrometry (LC/MS/MS), Publication EPA/600/R-08/092 Version 1.1.

- US EPA Method 821 (December 2011). Draft Procedure for Analysis of Perfluorinated Carboxylic Acids and Sulfonic Acids in Sewage Sludge and Biosolids by HPLC/MS/MS, Publication EPA-821-R-11-007.

- Western Australia Department of Environment Regulation (WA DER; January 2017). Interim Guideline on the Assessment & Management of Perfluoroalkyl & Polyfluoroalkyl Substances WA DER, US EPA Method 537 and US EPA Method 821.

- Current capabilities of analytical laboratories in Australia.

The laboratory is required to use NATA accredited methods based on NEPM, US EPA, Table B15 of US Department of Defence/Department of Energy (US DoD/DoE) and American Society for Testing and Materials (ASTM) methods as appropriate.

The laboratory shall undertake all PFAS analysis in accordance with Table B15 of US DoD/DoE QSM 5.1 and US EPA Method 821. Where the laboratory is currently using a method not in accordance with Table B15 of US DoD/DoE QSM 5.1 or USEPA 821 it should specify the methodology used, variation from Table B15 of US DoD/DoE QSM 5.1 or USEPA821 and capacity to modify current methods in accordance with Table B15 of US DoD/DoE QSM 5.1 or USEPA821.

Defence is aware that US EPA Method 537 is in the process of being updated to include modifications which have been incorporated into US DoD/DoE QSM 5.1. Following the release of US EPA Method 537 Defence will advise of any changes to the required analytical method as described above.

END OF TEXT