3.1 Project impacts

- Identification of WBACC independent adviser and approval to conduct investigation on aboriginal lands.
- Requirement to conduct the Numeriucal Groundwater Modelling and Human Health & Ecological Risk Assessment (HHERA).
- Outcomes of the investigation of the sewerage system at JBRF and treated effluent water distribution.
- SAQP Rev 2.1 and HHERA Plan reviews.

3.2 Project meetings

Project meetings held this reporting period are presented in Table 1.

Table 1: Summary of meetings held during the October reporting period

Meeting date	Meeting title	Participants	Minutes circulated
17 October 2017	PCG No 8	PCG members	Yes
Recurring Wednesday's	Weekly meetings	JBRF project team – Defence, GHD & Site auditor	Yes

3.3 Project deliverables submitted this period

Project deliverables submitted during this reporting period are presented in Table 2.

Table 2: Project deliverables submitted during the October reporting period

Document status	Title	Date submitted
Draft	HHERA Plan Rev 0.1	06/10/2017
Draft	Groundwater Modelling Plan Rev 1	06/10/2017
Final	Community Walk in session flyers	18/10/2017
Final	SAQP Sample locations A0 graphic	30/10/2017
Final	Results summary A0 graphic	30/10/2017
Draft	DSI presentation – Base briefing	31/10/2017
Draft	JBRF Creswell fact sheets for 06Nov17 CWIS	24/10/2017
Final	August report	09/11/2017
Final	PCG minutes	29/09/2017

3.4 Project Milestones

The following project milestones were achieved in the October reporting period:

- Development and issue of SAQP Rev 2.1 (Final) to Agencies and WBACC.
- Ongoing Sewerage treatment system investigation.
- Further development of HHERA and Numerical Groundwater Modelling plans.

4.0 Project Forecast

The project schedule is presented in the enclosed project schedule, dated 3 August 2017

4.1 Schedule tracking forecast

- SAQP (Rev 2.1) issued for Agency and WBACC review is expected to be finalised post WBACC review.
- Draft HHERA plan has been developed by GHD and issued to Defence and auditor for comment.
- Draft Numerical Groundwater Modelling plan has been developed by GHD and is undergoing update to incorporate Defence and auditor comment.

- The project schedule is impacted by the inability to access the Wreck Bay community land. Ongoing negotiations with WBACC are positive, with access to conduct sampling and investigation expected on post review of SAQP Rev 2.1.

4.2 Project deliverables expected next period

- Issue of HHERA Plan Rev 1
- Update of Groundwater numerical modelling plan

4.3 Technical Advisor forecast

The Technical Advisor's achievements and planned activities are presented in Table 3.

Table 3: Technical Advisor achievements and key activities during the August reporting period

Scope item	Achieved to date	Planned for next month
Monitor Project progress and provide comment	Yes	ongoing
Attend project and PCG meetings	Yes	ongoing
Review SAQP Rev 2.1 and provide comment	Yes	complete
Develop letter of endorsement for SAQP Rev 2.1	Yes	complete
Review HHERA plan Rev 0.1 and provide comment	Yes	ongoing
Review Groundwater model plan Rev 1 and provide comment	Yes	ongoing

5.0 Community enquiries

In this reporting period:

- No community independent enquiries were received via the Community Hotline (1800 987 618) and email (Jervisbay@ghd.com.au)
- Responses to communications with WBACC CEO received.
- There are 0 outstanding stakeholder enquires

6.0 Interaction with Government

Meetings and communications with Government stakeholders are summarised in Table 4.

Table 4: Summary of interactions with Government during the October reporting period

Meeting date	Meeting title	Participants	Minutes circulated
19 October 2017	PCG No 7	NSW & ACT Agencies	Yes

9.0 Requests for information from Defence

- All relevant reports and information associated with JBRF environmental assessments and contamination investigations have been provided to GHD by Defence.

10.0 Other Matters

- Nil

Yours sincerely

[redacted]

CC:

Enclosures: Project Milestone Schedule - Dated 15/11/2017

Project schedule, dated 15 November 2017

Item	Start	Finish	
SAQP	30/03/2017	15/09/2017	
WBACC, ACT & NSW Agencies review of Draft SAQP Rev 2	04/10/2017	14/11/2017	WBACC & Agencies
Finalise SAQP	TBC		GHD
Off Site Access	20/11/2017	01/03/2018	WBACC/Booderee/GHD/Defence
WBACC board meeting – sampling of 403 land	TBC		Defence/GHD
Approval to conduct Off-Site Groundwater Bore Installation, Soil, Sediment, surface water & Biota sampling	20/4/2017	01/03/2018	WBACC
DSI	5/04/2017	28/08/2017	GHD
On-Site Groundwater Bore Installation, Soil, Sediment and surface water sampling (Round 1).	5/04/2017	09/05/2017	GHD
On-Site Groundwater Bore Installation, Soil, Sediment and surface water sampling (Round 2).	TBA	TBA	GHD (rain event required)
On-Site additional investigations effluent water sampling.	12/09/17	TBA	GHD (rain event required)
Off-Site Groundwater Bore Installation, Soil, Sediment and surface water sampling (Round 1)	15/03/2018	20/06/2018	GHD
Off-Site Groundwater Bore Installation, Soil, Sediment and surface water sampling (Round 2)	15/03/2018	20/06/2018	GHD
Biota sampling	15/03/2018	06/06/2018	GHD
DSI Reporting	21/06/2018	23/10/2018	GHD/Defence/Agency/WBACC
DSI Report preparation	21/06/2018	06/08/2018	GHD
Defence and Auditor review of Draft DSI Report	07/08/2018	20/08/2018	Defence/Auditor
Update of Draft DSI Report	21/08/2018	28/08/2018	GHD
ACT & NSW State Agency review of DSI Report	29/08/2018	11/09/2018	Agency
WBACC Review of DSI report (If required)?	12/09/2018	02/10/2018	WBACC
Finalise DSI Report	03/10/2018	23/10/2018	GHD/Defence/Auditor

Human Health and ecological risk assessment	24/08/2017	30/09/2018	GHD/Defence/Agency/WBACC
HHERA Recommendation	18/07/2017	21/07/2017	GHD
HHERA Plan draft	24/08/2017	01/09/2017	GHD
Defence and Auditor review of Draft HHERA Plan	01/09/2017	15/10/2017	Defence/Auditor
ACT & NSW State Agency review of HHERA Plan	20/11/2017	01/12/2017	Agency
HHERA Implementation and Draft report	21/06/2018	29/08/2018	GHD
Defence and Auditor review of Draft HHERA report	30/08/2018	12/09/2018	Defence/Auditor
Update of Draft HHERA report	13/09/2018	20/09/2018	GHD
ACT & NSW State Agency review of HHERA	21/09/2018	04/10/2018	Agency
WBACC Review of HHERA report (If required)?	TBC	TBC	WBACC
Finalise HHERA Report	05/10/2018	18/10/2018	GHD/Defence/Auditor
Community Information Sessions	21/03/2017	25/05/2018	
Community Information Session 1	21/03/2017	21/03/2017	GHD/Defence/Agency/Community
Community Information Session 2	06/11/2017	06/11/2017	GHD/Defence/Agency/Community
Community Information Session 3	TBC	TBC	GHD/Defence/Agency/Community
Community Information Session 4 (Post DSI/HHERA report finalisation)	19/10/2018	19/10/2018	GHD/Defence/Agency/Community
Stakeholder engagement reporting	19/10/2018		GHD/Defence
Finalise stakeholder engagement reports	19/10/2018	31/12/2018	GHD/Defence
Meetings with Agencies	19/10/2018	31/12/2018	GHD/Defence/Agency
Project Close out	31/12/2018	18/01/2019	GHD/Defence

Stedman, Andrew (Health)

From: [redacted]>
Sent: Thursday, 23 November 2017 1:42 PM
To: [redacted]u; [redacted]u; Clapham, David; Chester, Heath; [redacted]u; [redacted]; Stedman, Andrew (Health); [redacted]
Cc: PFASIM Jervis Bay
Subject: JBRF HHERA plan Rev 1.1
Attachments: 2126171-REP-HHERA Plan Rev 1.1 Final_Reduced size.pdf

JBRF PCG,

Thank you for your time and inputs to date, for the Jervis Bay Range Facility PFAS investigation. Attached for your review and comment is the Human Health and Ecological Risk Assessment Rev 1.1 (HHERA). Please provide any comments to Defence by 08/12/17 at the address below.
pfasim.jervisbay@defence.gov.au
The attached file is reduced quality for ease of email transfer, should you require the original 17 Mb version, of higher resolution please contact me and I will arrange a large file transfer service.

Regards,

[redacted]

GHD
[redacted]
Level 2, 57 Graham Street (PO Box 621) Nowra NSW 2541 Australia | http://www.ghd.com/
Water | Energy & Resources | Environment | Property & Buildings | Transportation

Department of Defence

Jervis Bay Range Facility & HMAS Creswell
Human Health and Ecological Risk Assessment Plan and Methodology – Rev 1.1

November 2017

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Table index

Figure index

Appendices

1. Introduction

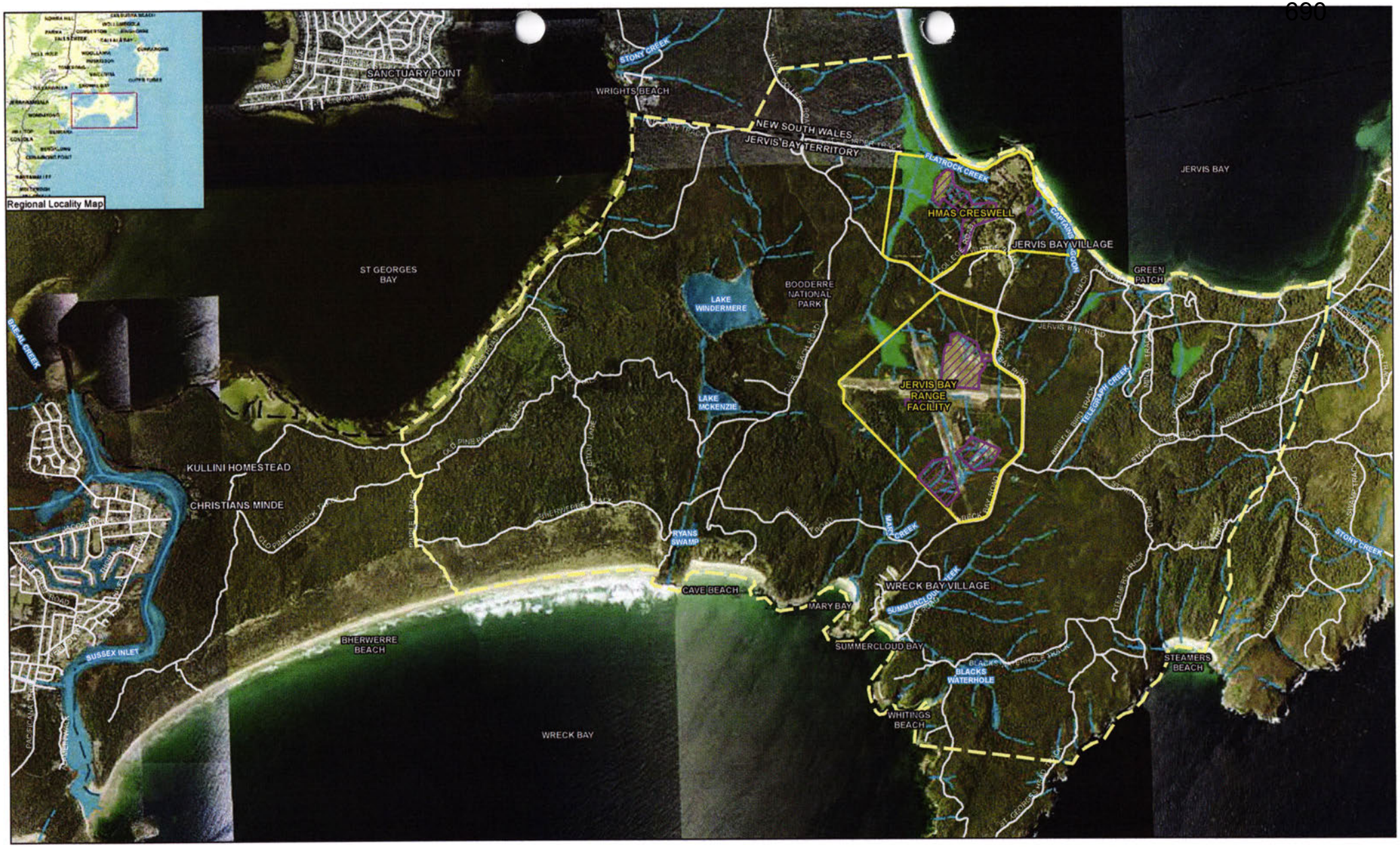
The Australian Department of Defence (Defence) commissioned GHD Pty Ltd (GHD) to undertake an Environmental Investigation associated with the historical use of Aqueous Film Forming Foam (AFFF) containing perfluoroalkyl and polyfluoroalkyl substances (PFAS) at Jervis Bay Range Facility (JBRF) and Her Majesty's Australian Ship (HMAS) Creswell (both collectively referred to as the site), in Jervis Bay Territory (JBT; Figure 1). The investigation work is underway and is being completed in two stages:

- Stage 1/preliminary site investigation (PSI): A preliminary program involving desktop study and site visit (refer to GHD 2017a).
- Stage 2/detailed site investigation (DSI): A detailed program of on-site soil, sediment, surface water and groundwater sampling and analysis, supplemented by additional off-site sediment, surface water, groundwater, and biota sampling and analysis.

GHD recently provided Defence with a formal recommendation with respect to the requirement for the completion of a Human Health and Ecological Risk Assessment (HHERA) (refer to GHD letter dated 18 July 2017 reference 2126171-60673). As outlined in the letter, detailed in a series of memos provided to Defence, and summarised in Section 2.5, analytical results received to date have exceeded the adopted PFAS human health and ecological based assessment criteria (derived from various published guidelines relevant to New South Wales and the Commonwealth). The PFAS has been identified in on-site soil, groundwater, and sediments and surface waters of Flat Rock Creek, Captains Lagoon and at the headwaters of Mary Creek.

Per the National Environment Protection (Assessment of Site Contamination) Measure (NEPM) 1999 (as amended 2013) *Schedule B1 Guideline on Investigation Levels for Soil and Groundwater,* a Tier 2 risk assessment (HHERA) is to be carried out when Tier 1 (default) investigation and screening levels (based upon a comparison of analytical results to published generic assessment levels) are exceeded. This is necessary as the generic assessment levels Tier 1 screening levels do not take into account site specific conditions including the receptors that could be exposed to contamination, the location of contamination and the pathways that could connect the sources and receptors. Therefore, GHD recommends that, upon completion of the DSI (i.e. once all soil, sediment, groundwater, surface water and biota analytical data has been received), a HHERA be completed.

This document has been prepared to outline to Defence and the various stakeholders, the proposed approach and preliminary methodology for the HHERA based on our current body of knowledge. It is important to note that upon completion of the DSI, including evaluation of all data and refinement of the Conceptual Site Model (CSM), the methodology for the HHERA will be reviewed and revised as necessary. This will include further consideration to specific receptor locations, exposure pathways and exposure concentrations.



Paper Size A3

0 245 490 980 1,470

Metres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

LEGEND

- Investigation Area Extent
- HMAS Creswell Site Boundary
- Jervis Bay Range Facility Boundary
- Areas of Environmental Concern
- Drainage Areas
- Water Bodies
- Major Waterways
- Minor Waterways / Drainage Lines
- Roads

Department of Defence

Job Number	21-26171
Revision	A
Date	26 Sep 2017

Site Location

Figure 1

G:\21\26171\GIS\Maps\Deliverables\21_26171_2001_SiteLocation.mxd

Data source: Imagery - ©Land and Property Information; (Extracted: 26/09/17); Streets, Waterways, Contours - NSW LPI 2015 DTDB. Created by: mweber

Level 15, 133 Castlereagh Street Sydney NSW 2000 T 61 2 9239 7100 F 61 2 9239 7199 E sydmail@ghd.com.au W www.ghd.com.au

1.1 Previous reports

The following reports have been prepared by GHD in relation to the site:

- GHD Pty Ltd (August 2017) *Jervis Bay Range Facility & HMAS Creswell Preliminary Site Investigation & Sampling, Analysis, and Quality Plan,* Revision 2 (GHD 2017a).
- GHD Pty Ltd (August 2017) *Water Use and Biota Survey, Jervis Bay Range Facility and HMAS Creswell – Jervis Bay Territory, Commonwealth of Australia – Report of Findings,* Revision 1 (GHD 2017b).
- GHD Pty Ltd (July 2017) *JBRF & HMAS Creswell – Recommendation for Human Health and Ecological Risk Assessment and Numerical Groundwater Model,* Revision 1 (GHD 2017c).

1.2 Background

AFFF has been used for fire-fighting purposes around Australia for decades. Depending on the type of AFFF used, the principal constituents (as active or by-product ingredients) may have included a range of contaminants of potential concern (COPCs), including perfluorooctane sulfonate (PFOS), perfluorooctanoic acid (PFOA) and fluorotelomers such as 6:2 fluorotelomer sulfonate (6:2 FTS) and 8:2 fluorotelomer sulfonate (8:2 FTS).

Due to the historical use of PFAS, PFOS and PFOA have been detected in soil, groundwater, sediments and surface water at some Defence bases. PFAS have also been detected in off-site areas at some of these locations. While the risks to human health and the environment from PFAS are still the subject of much research, PFAS are known to be persistent, bio-accumulative and toxic at elevated concentrations (DoEE 2016). Due to their persistence in the environment, PFAS can be transported long distances in water and air and transfer between different media (e.g. soil, sediment, surface water and groundwater; DoEE 2016).

Previous environmental investigations have been conducted at the site as part of the implementation of Defence's environmental strategy to minimise pollution from Defence activities. The most recent investigations (such as EES 2016) identified and assessed the presence of PFAS in soil, sediments, groundwater, and surface water as a result of former fire training activities. Based on a review of the previous environmental assessments and GHD's discussions with site personnel (as documented within GHD 2017a), eight key areas have been identified as the primary source of PFAS resulting from the historical on-site storage, use and disposal of AFFFs, namely:

- Area of Environmental Concern (AEC) A – the fire training area for the Royal Australian Navy School of Survivability and Ship Safety (RAN SSSS) (Defence Contaminated Sites Register [CSR] number SW0025);
- AEC B – Area adjacent to RAN SSSS, Mary Creek (Defence CSR number SW0026);
- AEC C – Former fire training area at JBRF;
- AEC D – Former 'exploded or demolished' building at JBRF;
- AEC E – Golf course down gradient of current fire station (Defence CSR number SW0035);
- AEC F – Fire Station (Defence CSR number SW0040);
- AEC G – Sewage Treatment Plant (STP) and outfall (Defence CSR number SW0217 and SW 0226); and
- AEC H – Drum disposal area (Defence CSR number SW0027).

AECs A, B, C, D, and H are located at JBRF, and AECs E, F, and G are located at HMAS Creswell (Figure 2).

A community water use and biota survey conducted with local residents from Jervis Bay Village and Wreck Bay Village obtained information from residents about water and land use at their properties across the investigation area. Results indicated that no respondents utilised groundwater from their properties, rather mains water is supplied by the Jervis Bay Territory Administration (JBTA) with water sourced from nearby Lake Windermere (this surface water feature does not appear to have been impacted by PFAS), and treated at the facility southwest of JBRF. Nevertheless, residents reported utilising surface water features including Mary Creek for drinking, cooking, washing, and swimming, while other surface water features such as Captains Lagoon were used for fishing or swimming. Upgradient surface water samples collected from drainage channels leading to these water features have been reported to be affected by PFAS (GHD 2016a). Risks to base personnel, local residents and the environment remain unquantified, although it is possible that PFAS contamination arising from the site could impact both human and ecological receptors.

1.3 Objective

The primary objective of the HHERA will be to evaluate the long-term risks to human and/or environmental receptors which may be exposed to PFAS.

1.4 Framework

Health and environmental risk assessments in Australia follow the methodology outlined in the National Environmental Protection Council (NEPC) (1999) *National Environment Protection (Assessment of Site Contamination) Amendment Measure 2013 (No. 1).*

Specifically, the Human Health Risk Assessment (HHRA) component will be undertaken in accordance with the approach and guidance recommended in the following references:

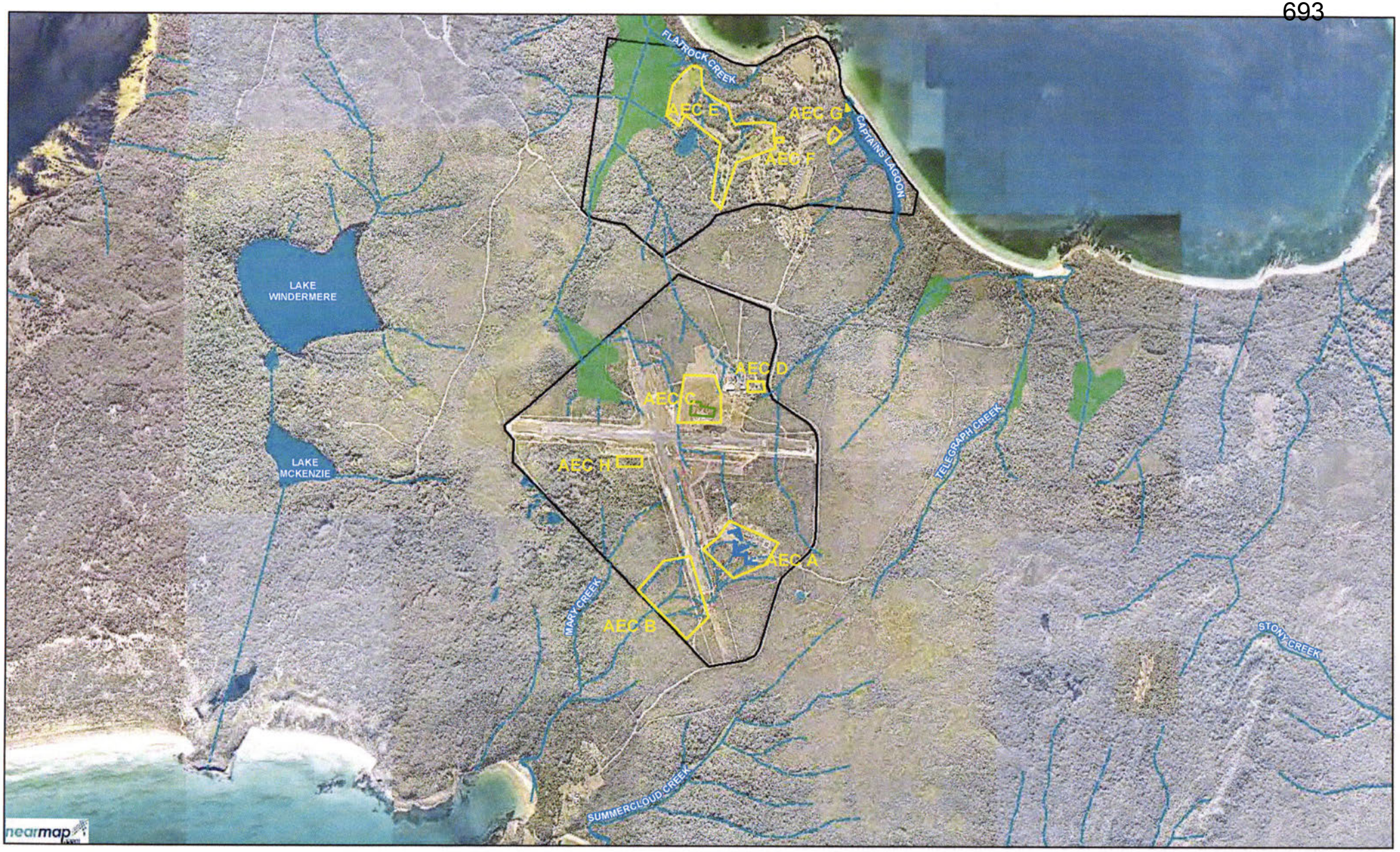
- enHealth (2012) *Environmental Health Risk Assessment, Guidelines for Assessing Human Health Risks from Environmental Hazards*;
- NEPC (2013) *Schedule B4, Guideline on Site-Specific Health Risk Assessment Methodology*; and
- NEPC (2013) *Schedule B7, Guideline on Health-Based Investigation Levels.*

The Ecological Risk Assessment (ERA) component will be undertaken in accordance with the approach and guidance recommended in the following references:

- Australian and New Zealand Environmental and Conservation Council (ANZECC) and Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ) (2000) *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*; and
- NEPC (2013) *Schedule B5a, Guideline on Ecological Risk Assessment.*

1.5 Scope of this document

This plan outlines the steps to be undertaken in the development of both the HHRA and ERA. This includes a summary of the CSM, identifying potential sources, receptors, and anticipated transport pathways at the site, proposed data collection and evaluation methodology (drawn from the SAQP submitted in August 2017), and the proposed approach for both the HHRA and ERA, including problem identification, exposure assessment, toxicity assessment, and risk characterisation.



Paper Size A3

0 150 300 600 900

Metres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

LEGEND

- Jervis Bay Range Facility
- HMAS Creswell
- Areas of Environmental Concern - JBRF
- Areas of Environmental Concern - Creswell
- HATS Site Area
- Water Bodies
- Major Waterways
- Drainage Areas
- Minor Waterways / Drainage Lines

Department of Defence

Source Areas

Job Number 21-26171
Revision
Date 29 Aug 2017

Figure 2

G:\21\26171\GIS\Maps\Deliverables\21_26171_Z003_SiteDetailed.mxd

Data source: Imagery - Nearmap (Imagery Date: 2016/08/14); Streets, Waterways - NSW LPI 2015 DTDB; Contours - NSW LPI 2016. Created by tnhem

Level 15, 13[illegible] Pereagh Street Sydney NSW 2000 T 61 2 9239 7100 F 61 2 9239 7199 E sydmail@ghd.com.au W www.ghd.com.au

2. Summary of conceptual site model

GHD has prepared a detailed CSM which provides a conceptual understanding of the pathways via which identified receptors at the site and in surrounding areas, may be exposed to PFAS.

The scope of work undertaken to develop the CSM comprised the following:

- Assessment of the sources and extent of known contamination,
- Identification of known contaminant transport pathways,
- Compilation of information currently available with regard to human and ecological receptors at the site and surrounding areas,
- Determination of potentially complete exposure pathways, and
- Compilation of a detailed CSM for the site and surrounding areas.

The identified sources, receptors, transport pathways and exposure pathways for human and ecological receptors both on- and off-site are summarised in the sections below. The CSMs are presented graphically in Figures 3a to 3d (human receptors and exposure pathways) and Figures 4a to 4d (ecological receptors and exposure pathways).

2.1 Sources

The main source areas were associated with fire training activities using AFFF along with other various point sources from associated storage areas, disposal areas and to a lesser degree, miscellaneous, undocumented incidents, as described in Table 1.

Table 1 Summary of sources

On-site	Off-site
JBRF	Marine sediments (if affected) are expected to be an on-going secondary source of PFAS to the marine environment (secondary source).
AEC A – RAN SSSS (Defence CSR number SW0025)	
AEC B – Area adjacent to RAN SSS, Mary Creek (Defence CSR number SW0026)	
AEC C – Former fire training area of the now parachute training school	
Area D – Former asbestos Building 15 (Defence CSR number SW0035)	
Area H – Former drum disposal area (Defence CSR number SW0027)	
HMAS Creswell	
Area E – Golf course (Defence CSR number SW0035, secondary source)	
Area F – Fire station (Defence CSR number SW0040)	
Area G – STP and outfall (Defence CSR numbers SW0217 and SW0226, secondary source)	

2.2 Receptors

Based on currently available information with regard to the current and ongoing use of the site and the current land uses of the surrounding areas, the identified human and ecological receptors are summarised in Table 2.

Table 2 Summary of likely human and ecological receptors

On-site		Off-site	
Human	Ecological	Human	Ecological
Base personnel	Plants, trees, grasses	Wreck Bay Village Residents	Plants, trees, grasses
Jervis Bay Village Residents*	Lower order species e.g. insects, crustaceans	Booderee National Park workers	Lower order species e.g. insects, crustaceans
Maintenance workers/ contractors	Higher order species e.g. fish, birds, mammals	Recreational users	Higher order species e.g. fish, birds, mammals
Visitors	Groundwater aquifer	Jervis Bay Village residents (including school children or teachers/workers at the Jervis Bay Village School or Jervis Bay Village Police Station)*	Groundwater aquifer
	Surface water bodies		Surface water bodies, including marine

*Note that Jervis Bay Village straddles the boundary of HMAS Creswell and therefore, individuals residing in this area may be both on- and off-site human receptors.

2.3 Transport pathways

Potential transport pathways by which PFAS introduced to the environment may migrate within, and from the site are summarised in Table 3.

Table 3 Summary of identified transport pathways

On-site only	On- and Off-site
Wind dispersion of AFFF	Lateral migration of groundwater
Wind erosion of impacted surface soils	Groundwater entering surface water bodies
Leaching from infrastructure to surface runoff and adsorption to soil	Infiltration and leaching from soils/sediments to groundwater
Vertical migration through soil profile	Leaching from soils/ sediments to surface water
Discharge from the sewer treatment plant at JBRF and subsequent irrigation of the golf course.	Surface water runoff
	Adsorption to soil and sediments from surface water
	Adsorption from shallow groundwater onto surface soils

On-site only	On- and Off-site
	Build-up of PFAS within sediments at the groundwater-salt water wedge
	Uptake into flora and fauna

2.4 Complete exposure pathways

The following exposure pathways are considered to constitute complete exposure links to the media that may contain PFAS. The risk to receptors, however, can only be quantified through the collection and analysis of samples of the various media and comparison to established and endorsed investigation levels or through completing the human and ecological risk assessments.

Given that the contamination is from historical use of AFFF, it is anticipated that three chemicals (PFOS, PFHxS, PFOA) will make up more than 90% of the source concentration/mass. In this case, there is no requirement to assess quantitatively the other components of PFAS in the HHERA.

However, should sampling results indicate PFAS other than the primary three compounds contribute a more significant component (>10% of total), then the relative toxicity of these components will be assessed. If the >10 % figure is achieved GHD will apply toxic equivalency factors (TEFs) to other PFAS chemicals as a conservative factor. Consideration will be given to toxicity reference values presented in guidelines published by international agencies, such as the Texas Commission on Environmental Quality (TCEQ) in order to derive toxic equivalency (TEQ) for other PFAS compounds.

2.4.1 Human

The principal exposure pathway associated with PFAS is considered to be via surface water ingestion or consumption of affected biota. Health impacts from exposure to PFAS via dermal contact and inhalation (via dust) are not considered to be a major pathway given the low dermal absorption of PFAS and its low volatility, but for completeness have been recognised as potential inputs into the risk assessment. Ingestion may occur from handling or using contaminated soils or surface water, consumption of biota (marine, freshwater, or terrestrial) or home grown produce (such as fruit and vegetables) exposed to contaminated waters, or incidental intake from impacted surface waters. Sampling to date has demonstrated that direct contact and ingestion of tap water (sourced from Lake Windermere off-site) are not relevant exposure pathways.

Potential exposure pathways for both on- and off-site receptors are summarised as follows:

On-site

- Dermal contact with and incidental ingestion of soil. Specifically, dermal contact could occur through excavations, drilling, grounds maintenance, transport or otherwise handling of impacted soils.
- Dermal contact with and incidental ingestion of groundwater. Groundwater is not abstracted on-site but the water table rises above the ground level and perched groundwater has been observed to pool overland (anecdotal evidence from discussion with base personnel).
- Dermal contact with and incidental ingestion of surface water and sediments.
- Dermal contact with and incidental inhalation of water mist from golf course sprinklers (using effluent from AEC G STP).

- Inhalation of dust generated from surface soils.
- Ingestion of affected flora (including home grown produce), marine or freshwater biota.
- Ingestion by infants of breast milk (if mothers have consumed impacted food items).
- Direct contact and ingestion of tap water (sourced from Lake Windermere off-site).

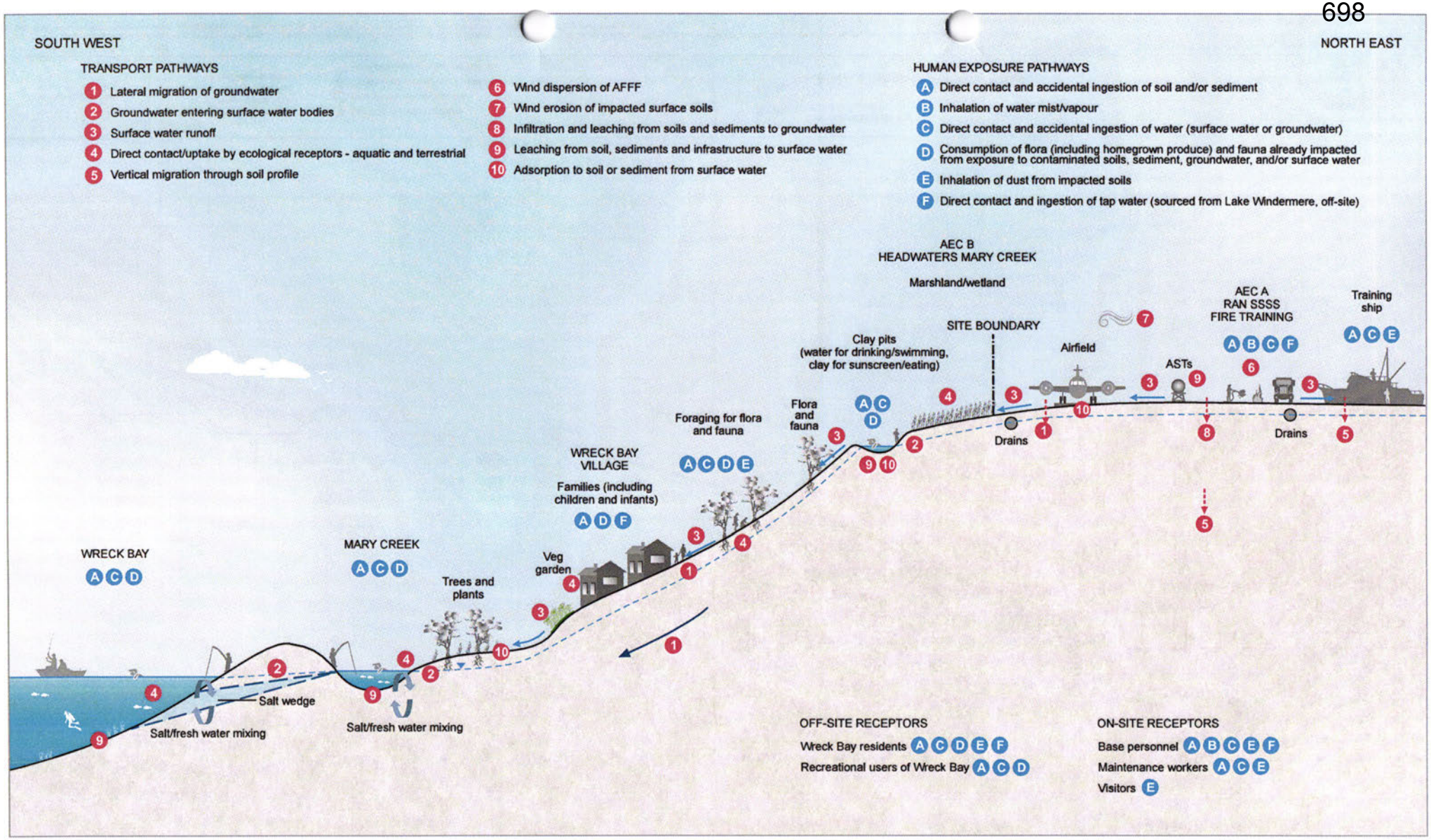
Off-site

- Dermal contact with and incidental ingestion of soil.
- Dermal contact with and incidental ingestion of groundwater. Groundwater is not abstracted on-site but the water table rises above the ground level and perched groundwater has been observed to pool overland (anecdotal evidence from discussion with base personnel).
- Dermal contact with and incidental ingestion of surface water and sediments.
- Inhalation of dust generated from surface soils.
- Ingestion of affected flora (such as geebungs, berries, lilli pillies, passionfruit, etc., or home grown produce), marine or freshwater biota, culturally significant terrestrial organisms, or ingestion by infants of breast milk (if mothers have consumed impacted food items).

2.4.2 Ecological

The identified ecological receptors may be exposed through one or more of the following exposure pathways:

- Direct contact and uptake of:
    - Soil,
    - Surface water and sediments (including pore water),
    - Groundwater; and
- Consumption of flora and fauna already affected from exposure to potentially contaminated soil, groundwater, sediment and/or surface water.



Conceptual schematic only - not to scale

LEGEND
Groundwater flow
Groundwater table
Surface water flow
Vertical migration
Wind
Complete transport pathway
Incomplete transport pathway
Complete human exposure pathway
Incomplete human exposure pathway

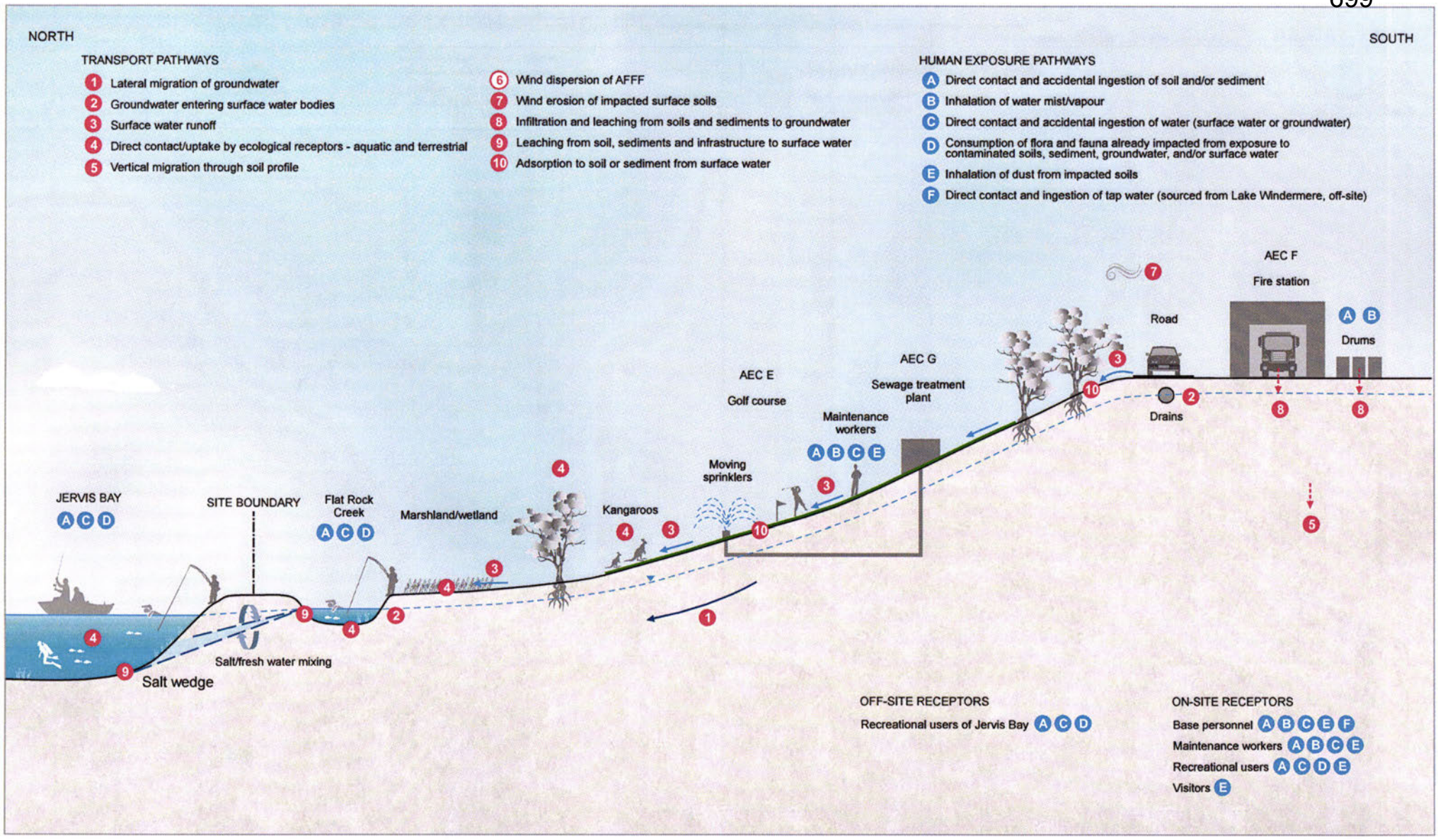
Department of Defence
JBRF to Wreck Bay

HHRA Conceptual Site Model

Job Number 2126171
Revision A
Date 31 Oct 2017

Figure 3A

AU\Launceston\Projects\21\26171\126171_LTN_07.cdr
Level 15, 133 Castlereagh Street Sydney NSW 2000 T 61 2 9239 7100 F 61 2 9239 7199 E sydmail@ghd.com W www.ghd.com



Conceptual schematic only - not to scale

LEGEND

- Groundwater flow
- Groundwater table
- Surface water flow
- Vertical migration
- Complete transport pathway
- Incomplete transport pathway
- Complete human exposure pathway
- Incomplete human exposure pathway

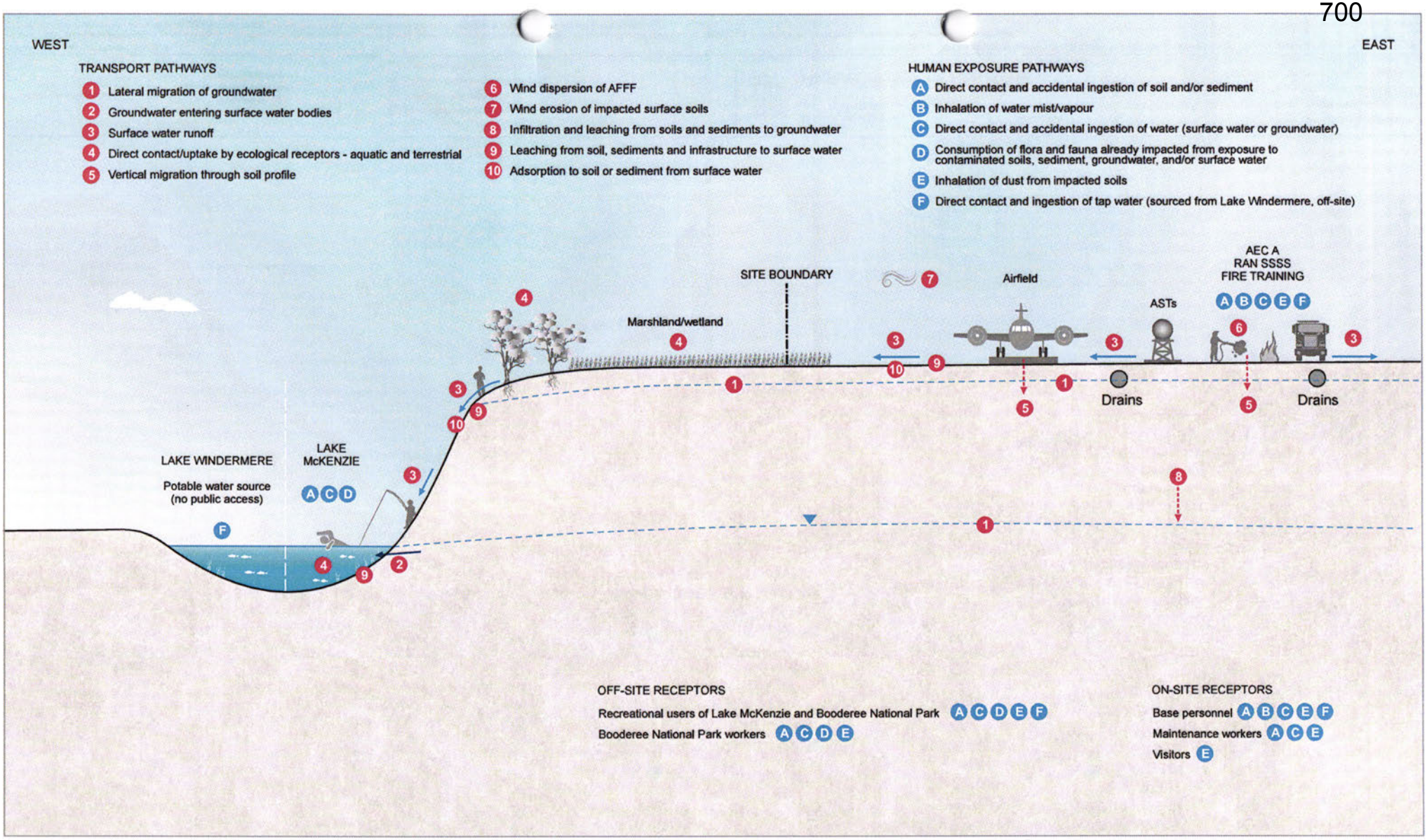
Department of Defence
HMAS Creswell

HHRA Conceptual Site Model

Job Number 2126171
Revision A
Date 31 Oct 2017

Figure 3B

Level 15, 133 Castlereagh Street Sydney NSW 2000 T 61 2 9239 7100 F 61 2 9239 7199 E sydmail@ghd.com W www.ghd.com



Conceptual schematic only - not to scale

LEGEND

Groundwater flow
Groundwater table
Surface water flow
Vertical migration
Wind
Complete transport pathway
Incomplete transport pathway
Complete human exposure pathway
Incomplete human exposure pathway

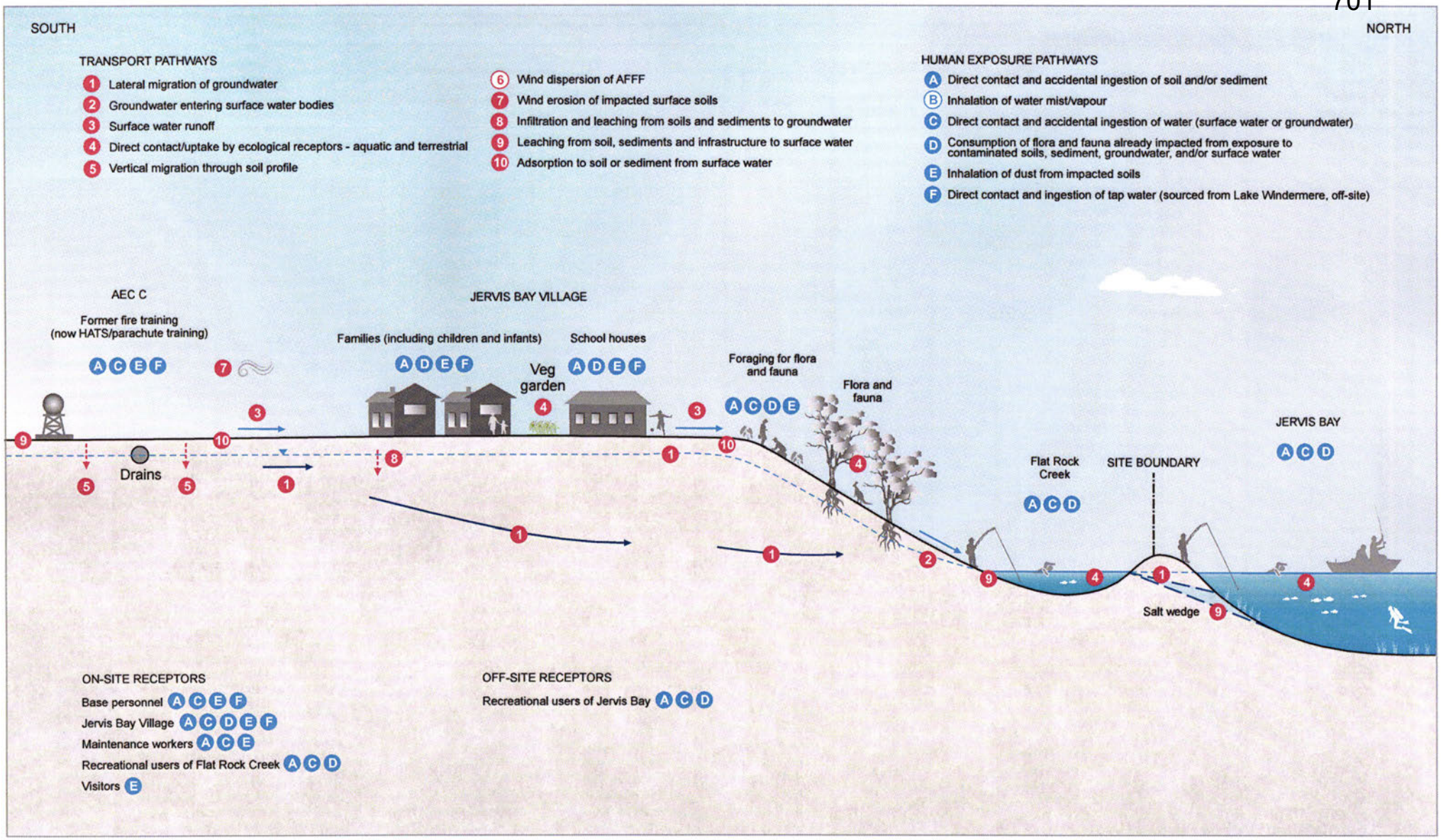
Department of Defence
JBRF to Lake Windermere

HHRA Conceptual Site Model

Job Number	2126171
Revision	A
Date	31 Oct 2017

Figure 3C

AU\Launceston\Projects\21\26171\2126171_LTN_09.cdr
Level 15, 133 Castlereagh Street Sydney NSW 2000 T 61 2 9239 7100 F 61 2 9239 7199 E sydmail@ghd.com W www.ghd.com



Conceptual schematic only - not to scale

LEGEND

Groundwater flow
Groundwater table
Surface water flow
Vertical migration
Wind
Complete transport pathway
Incomplete transport pathway
Complete human exposure pathway
Incomplete human exposure pathway

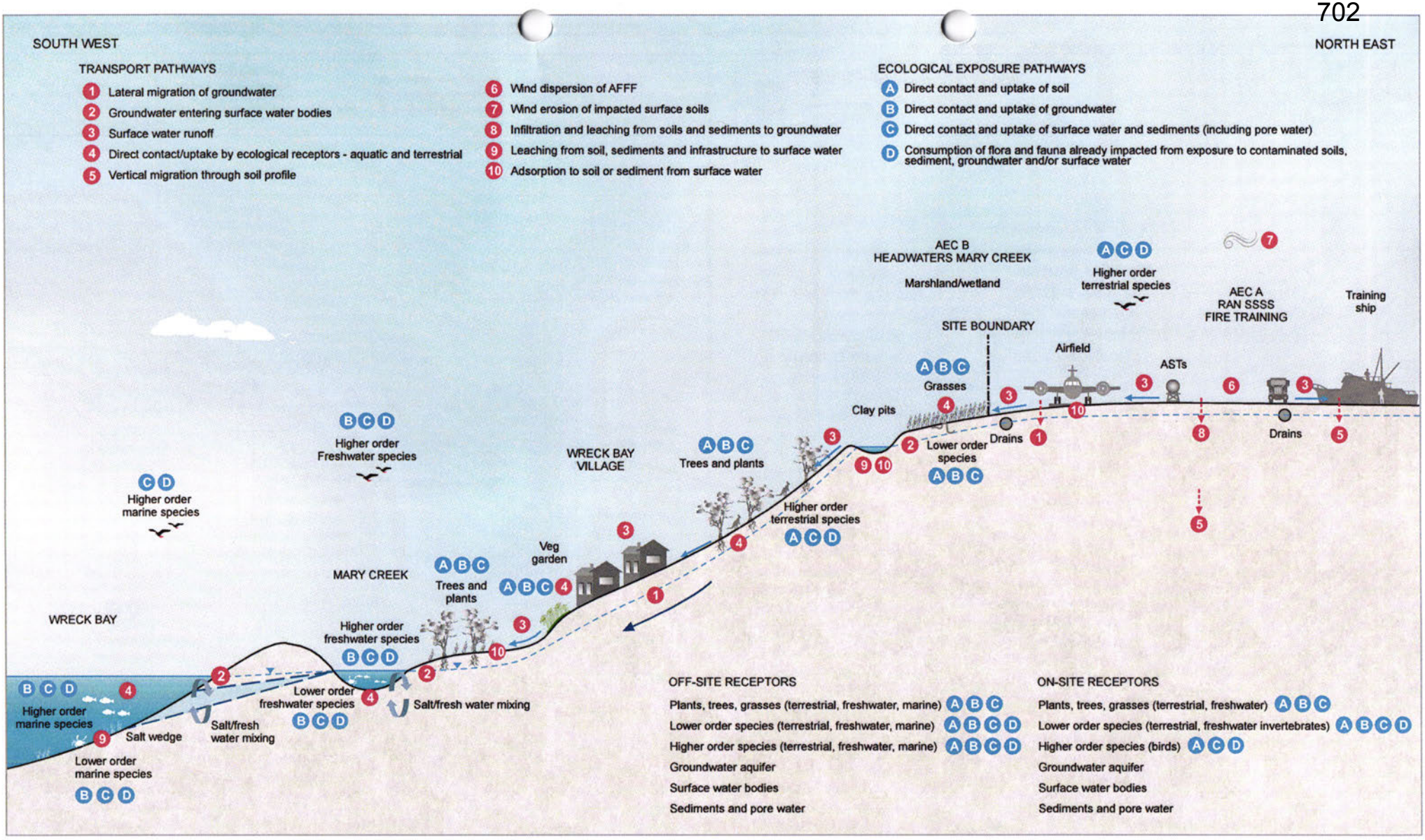
Department of Defence
JBRF to Jervis Bay Village

HHRA Conceptual Site Model

Job Number 2126171
Revision A
Date 31 Oct 2017

Figure 3D

Level 15, 133 Castlereagh Street Sydney NSW 2000 T 61 2 9239 7100 F 61 2 9239 7199 E sydmail@ghd.com W www.ghd.com



Conceptual schematic only - not to scale

Groundwater flow
Groundwater table
Surface water flow
Vertical migration
Wind
Complete transport pathway
Incomplete transport pathway
Complete ecological exposure pathway

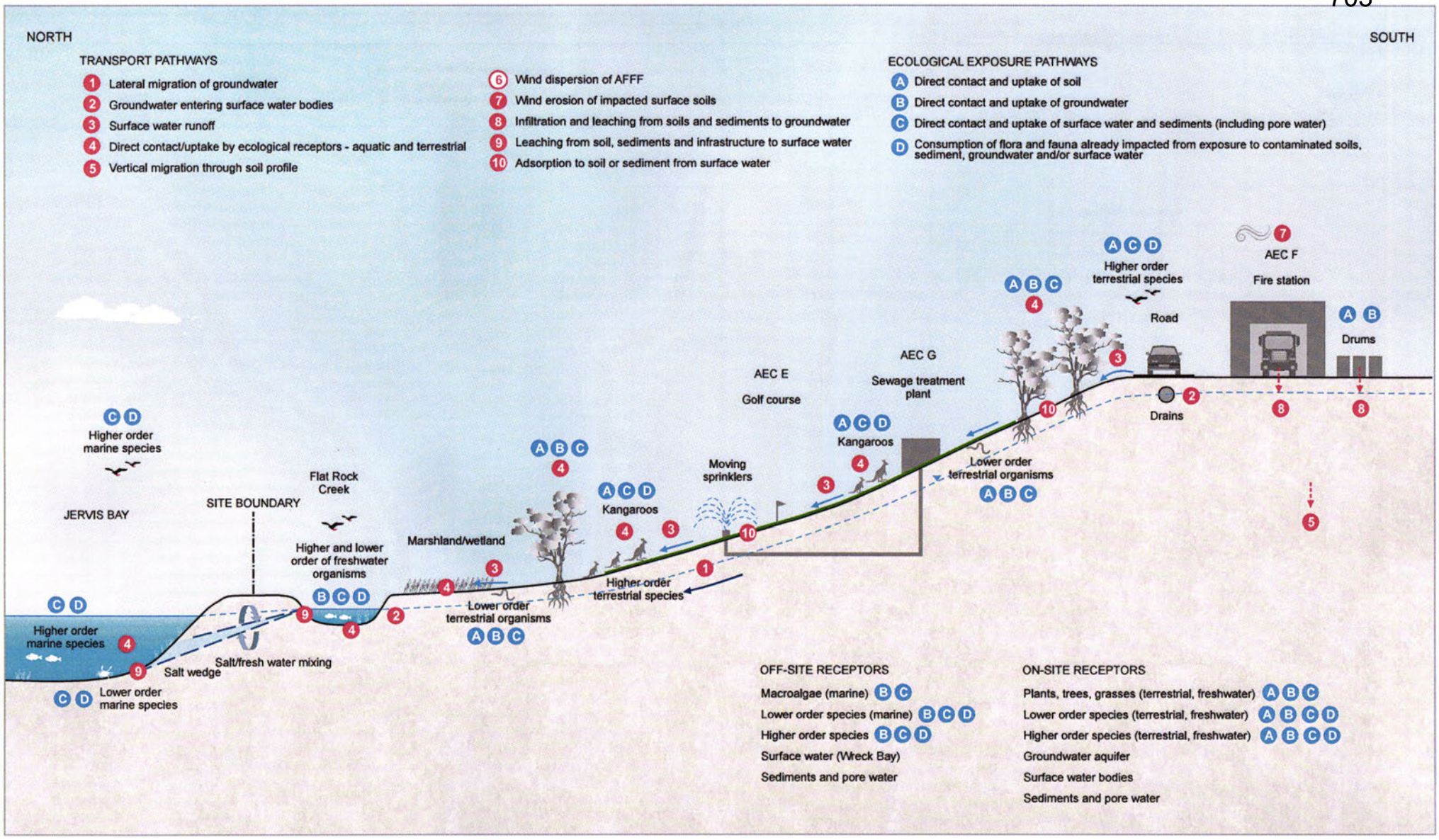
Department of Defence
JBRF to Wreck Bay

ERA Conceptual Site Model

Job Number	2126171
Revision	A
Date	31 Oct 2017

Figure 4A

AU\Launceston\Projects\21\26171\126171_LTN_11.cdr
Level 15, 133 Castlereagh Street Sydney NSW 2000 T 61 2 9239 7100 F 61 2 9239 7199 E sydmail@ghd.com W www.ghd.com



Conceptual schematic only - not to scale

Groundwater flow
Groundwater table
Surface water flow
Vertical migration
Wind
Complete transport pathway
Incomplete transport pathway
Complete ecological exposure pathway

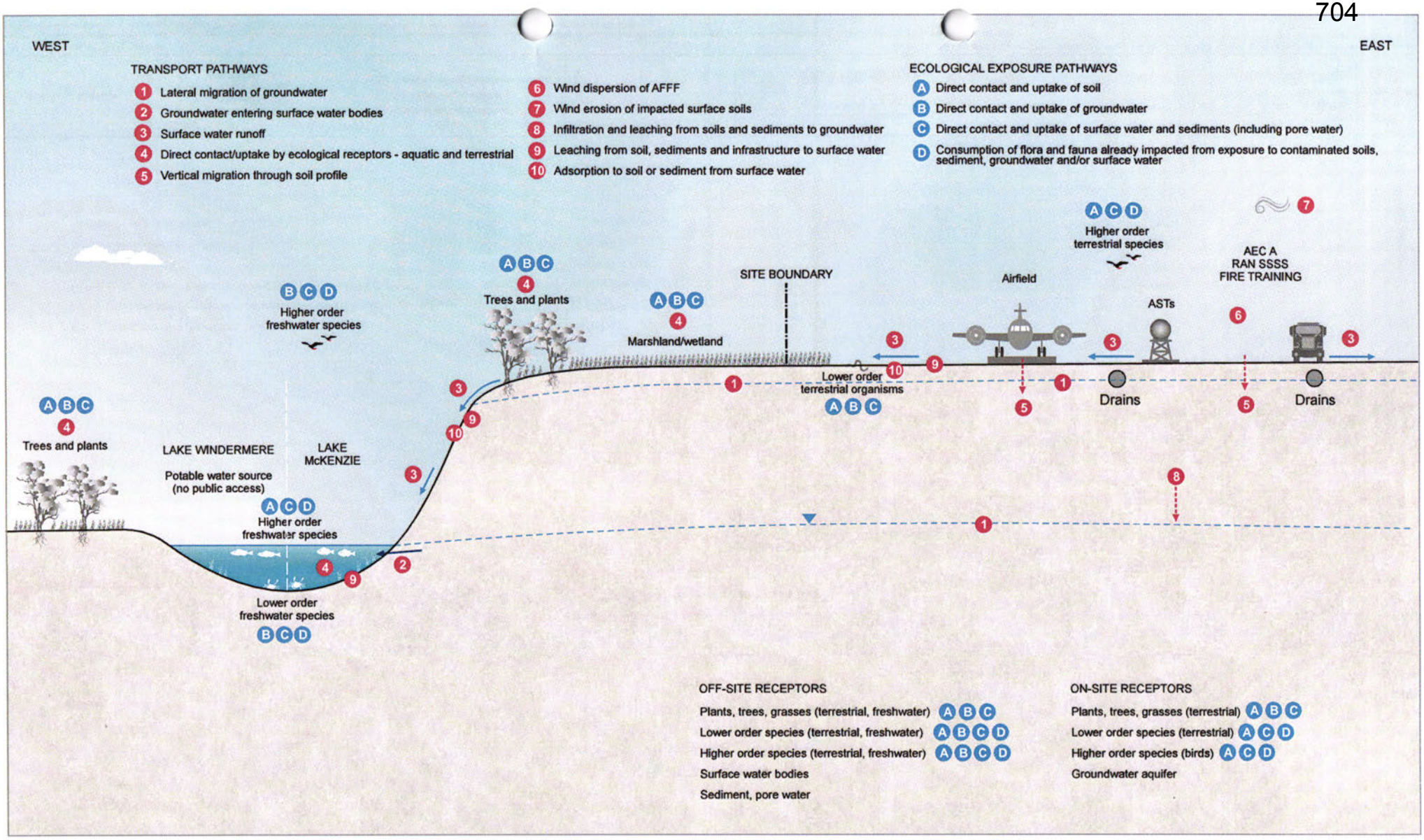
Department of Defence
HMAS Creswell

ERA Conceptual Site Model

Job Number 2126171
Revision A
Date 31 Oct 2017

Figure 4B

Level 15, 133 Castlereagh Street Sydney NSW 2000 T 61 2 9239 7100 F 61 2 9239 7199 E sydmail@ghd.com W www.ghd.com



Conceptual schematic only - not to scale

Groundwater flow
Groundwater table
Surface water flow
Vertical migration
Wind
Complete transport pathway
Incomplete transport pathway
Complete ecological exposure pathway

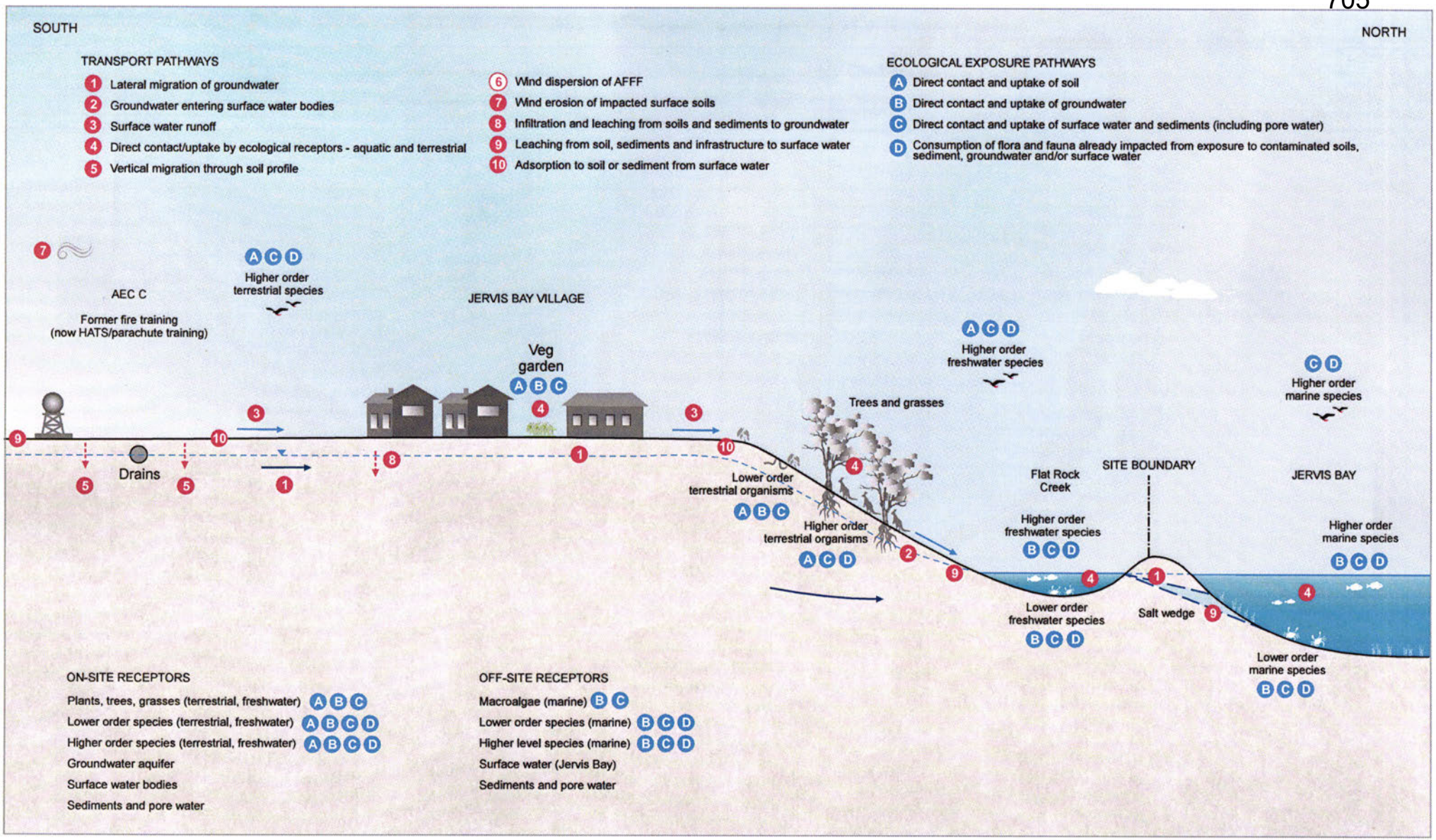
Department of Defence
JBRF to Lake Windermere

ERA Conceptual Site Model

Job Number	2126171
Revision	A
Date	31 Oct 2017

Figure 4C

AU\Launceston\Projects\21\26171\126171_LTN_13.cdr
Level 15, 133 Castlereagh Street Sydney NSW 2000 T 61 2 9239 7100 F 61 2 9239 7199 E sydmail@ghd.com W www.ghd.com



Conceptual schematic only - not to scale

LEGEND
Groundwater flow
Groundwater table
Surface water flow
Vertical migration
Wind
Complete transport pathway
Incomplete transport pathway
Complete ecological exposure pathway

Department of Defence
JBRF to Jervis Bay Village

ERA Conceptual Site Model

Job Number 2126171
Revision A
Date 31 Oct 2017

Figure 4D

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2.5 Findings to date

Sampling conducted to date has included on-site soil, groundwater, surface water and sediment at JBRF and HMAS Creswell. The sampling has been conducted in accordance with the sampling analysis quality plan (SAQP) prepared by GHD (2017a).

PFAS has been detected across the site in soil, surface water, sediment and groundwater. Generally, PFOS and perfluorohexane sulfonate (PFHxS) were observed more frequently than PFOA or precursor compound 6:2 fluorotelomer sulfonate (6:2FTS). These results are from GHD's on-site sampling program undertaken April to August 2017, the results of which have been submitted to Defence in a series of memoranda. Results will be detailed in future reports but are summarised below. Relevant figures are included in Appendix A for reference.

Soil and Sediment

- All recorded concentrations of 6:2FTS in soil and sediment samples were less than the nominated investigation level of 900 mg/kg (for industrial soil; DCD #8 2015), with the highest concentration being 0.0071 mg/kg.
- All recorded concentrations of PFOA in soil and sediments were less than the nominated investigation level of 240 mg/kg (for industrial soil; DCD #8 2015), with the highest concentration being 0.194 mg/kg.
- All recorded concentrations of PFOS and perfluorohexane sulfonate (PFHxS) (combined) were less than the nominated investigation level of 90 mg/kg (for industrial soil; DCD #8 2015) However, one sample at JBRF exceeded the nominated ecological investigation level for direct toxicity of on-site soils in national parks or areas of high ecological value (6.6 mg/kg; OEH 2017). While there is no criteria for PFAS in sediments, one sediment sample exceeded the proposed sediment screening level of 0.22 mg/kg (see Section 5.5).

Groundwater and Surface Water

- All recorded concentrations of 6:2FTS in surface water and groundwater samples were less than the nominated investigation level of 5.0 µg/L (DCD #8 (Amendment 1) 2016), with the highest concentration being 0.144 µg/L.
- All recorded concentrations of PFOA were less than the nominated on-site investigation level of 5.6 µg/L (as drinking water is not sourced on-site; FSANZ 2017).
- The sum of PFOS and PFHxS was detected in all but one sample, with a maximum concentration of 120 µg/L. Approximately 37% of surface water samples (43% from HMAS Creswell) are in excess of the nominated on-site investigation level of 0.7 µg/L (recreational value as drinking water is not sourced on-site; FSANZ 2017). Three groundwater and four freshwater samples had PFOS+PFHxS concentrations in excess of the Defence ecological surface and groundwater assessment level of 6.6 µg/L, as presented in DCD #8 (2015) . All surface water samples had concentrations of PFOS+ PFHxS in excess of the ecological assessment level for fresh water for 99% species protection of 0.00023 µg/L (OEH 2017). Approximately 78% of samples are in excess of the 95% species protection value of 0.13 µg/L, and 13% of samples are in excess of the 90% species protection value of 2.0 µg/L (OEH 2017). It is assumed that the inflow areas of Flat Rock Creek and Captains Lagoon are estuarine in nature. Five of the 11 locations in these waterways had concentrations in excess of the investigation levels for 99% species protection for marine organisms of 0.29 µg/L; no concentrations were in excess of the 95% species protection level of 7.8 µg/L (CRC Care, 2017b).

Future sampling occurring off-site will be undertaken for soil, sediment, groundwater, surface water, and biota (GHD 2017a), the results of which will be considered in the proposed HHERA.

3. Data collection and evaluation

3.1 Data inputs

3.1.1 Sampling analysis quality plan (GHD 2017a)

All data obtained during the DSI will be considered (as relevant) within the HHERA. The DSI is currently in preparation in accordance with the SAQP prepared by GHD (2017a). The following data has been obtained to date, as per the SAQP:

- On-site groundwater quality data from the sampling of the eight source areas and around the site boundary described in Section 2.1 (completed in April to August 2017);
- On-site soil and sediment quality data from the sampling of the eight source areas to assess the pathways across the site described in Section 2.1 (completed in April to August 2017);
- Concrete samples collected from AEC A, AEC C, and AEC F (completed in April to August 2017); and
- Surface water and sediment quality data from the sampling of on-site drainage channels and creeks (completed in April to August 2017).

Collection of the following data is also proposed and will be completed beginning in October and November 2017 (TBC):

- Off-site groundwater quality data from existing and groundwater monitoring wells to be installed;
- Groundwater quality data representative of groundwater migrating off-site via the sampling of groundwater monitoring wells (existing and to be installed) at the site boundary;
- Off-site soil and sediment quality data down gradient of the site;
- Off-site surface water and sediment quality data from downstream receptors and off-site drainage channels;
- Produce from resident vegetable gardens; and
- Biota data from the sampling of species within Flat Rock Creek, Marys Creek, Lake McKenzie, Jervis Bay, and Wreck Bay.

3.1.2 Reference data

Additionally, data available from the following environmental reports previously prepared in relation to the use of AFFF at the site will be considered, where relevant, when undertaking the HHERA:

- Biosis Pty Ltd, *HMAS Creswell Boardwalk and Bridge: Flora and fauna assessment*, June 2015
- Coffey Partners International Pty Ltd, *Geotechnical & Environmental Works – Detailed Investigation, Air 9000 Phase 7 Helicopter Aircrew Training System (HATS), HMAS Albatross & Jervis Bay Airfield*, December 2014
- Environmental Earth Sciences, *Contaminated soil and water management plan- AIR 9000 phase 7 helicopter aircrew training system (HATS), Jervis Bay Airfield*, October 2016
- Environmental Water, *ACT Government Jervis Bay water sampling data*, 2016

- ERM, *HMAS Creswell and Jervis Bay Range Facility – remnant vegetation survey*, June 2002
- ERM, *HMAS Creswell and Jervis Bay Range Facility – threatened fauna protection plan*, June 2002.
- GHD Pty Ltd, *PFAS environmental management preliminary sampling program,* September 2016
- Gooden Mackay Logan, *South Jervis Bay Heritage Handbook*, June 2006
- PPK Environment & Infrastructure, *JBRF Mary Creek and Headwaters Remediation Project – Preliminary Environmental Site Assessment Report*, September 2001
- Sinclair Knight Merz Pty Ltd (SKM), *HMAS CRESWELL, Jervis Bay Range Facility and Bherwherre Ridge Communication Facility – Terrestrial Fauna Survey and Habitat Assessment*, June 2006
- Synergy Resource Management, *water treatment plan daily summary*, 2017

Note that this list is not exhaustive. A detailed review of relevant reports was conducted as part of the PSI and a summary of each report is provided within the PSI report (GHD 2017a).

3.2 Sampling design

The sampling design is based on the source, pathway and receptor identification as per the CSM report (GHD 2017a) and the summarised CSM is presented in Section 2. The sampling rationale and proposed sampling program was detailed in the SAQP report (GHD 2017a). Nonetheless, the sampling program has been summarised in Table 4 below, inclusive of the additional proposed sampling program outlined in Section 3.1.1.

It should be noted that due to the judgemental and iterative nature of the proposed sampling program, access to privately owned properties and the presence of adequate, representative media to sample there is the possibility of variations from the SAQP proposed sampling locations. For complete discussion regarding sampling methodology, please refer to the SAQP (GHD 2017a).

3.2.1 Data gaps and limitations

The following potential data gaps to the investigation design were identified and are summarised below:

- Access to locations within Booderee National Park will be dependent on approvals and accessibility by foot. Locations may alter if access or approval is not granted.
- Success of biota sampling will vary by location based upon species abundance, weather conditions, and other unforeseeable variation. Sample collection will adhere to the SAQP, with any changes reported to the Defence Project Manager, Site Auditor, and Department of Primary Industries (DPI) contact, if applicable, before proceeding.
- While the collection of lower trophic level organisms fills a data gap in the literature and can be used to extrapolate concentrations expected in higher level organisms (and thus reduce any sampling impact on higher level vertebrates such as birds or larger mammals), the use of models results in inherent uncertainty. Regardless, the current sampling plan encompasses a wide array of organisms, and provides a comprehensive snapshot of exposure to the ecosystem, providing a strong foundation for ecological and human health considerations.

Table 4 Sampling program (per GHD, 2017a)

Location	Soil program	Groundwater program	Sediment and surface water program	Biota Sampling
Source delineation				
JBRF				
AEC A – RAN SSSS (SW0025)	*Initial sampling event:* Soil sampling will be conducted from 28 investigation locations in and around the current and former RAN SSSS to a maximum depth of 1 m. Soil samples will be collected at surface, 0.5 m and 1 m from a drill rig (push tube core). Six groundwater boreholes will be installed, and soil samples will be collected via direct push methodology to allow for collection of undisturbed samples at surface, 0.5 m, 1 m, and every metre after. *Second sampling event* Based on the initial sampling event, an additional 12 boreholes and 3 groundwater boreholes are to be drilled during a second mobilisation to provide delineation of source areas impacts. In summary, the soil and concrete investigation will include: - Drilling of 40 soil boreholes. - Drilling and installation of 9 groundwater boreholes. - Collection of 10 concrete samples. Across the two events, a total of ten concrete samples will be collected from selected locations within the hardstand to test for the impacts and leachability of the concrete capping. Waste soils for the installation of groundwater wells will be collected and stored on-site in drums. Boreholes have been named A_BH01 to A_BH40 and A_MW01 to A_MW09. Collection of one concrete sample from a stockpile of concrete (AEC A_concrete_SP).	Install a total of 9 groundwater wells (to a maximum depth of 3 m) over two mobilisations. The second mobilisation is to provide delineation upon receipt of the initial dataset. The groundwater monitoring wells will be developed initially using mechanical surging techniques, groundwater will be collected and stored on-site in drums. GHD will sample and analyse groundwater samples collected from each of nine newly installed wells and one existing well (MW024). In summary, the groundwater investigation will include: - Nine new wells - One existing well	Collection of five water samples from four holding tanks of the closed water circuit system within the RAN SSSS; pit tank S440, training water holding tank S415, SLSRTU holding tank S439, DLSTRU S481, Fire main water tank S416. Sample locations have been named A_S440_SW01, A_S415_SW02, A_S439_SW03, A_S481_SW04, and A_S416_SW05.	None
AEC B – Area adjacent to RAN SSSS, Mary Creek (SW0026)	Soil sampling will be conducted from ten hand auger locations to a maximum depth of 1 m. Samples will be collected from surface and 0.5 m. Hand auger locations are to cover a broad grid and follow transects of drainage lines leading from the runway to Mary Creek. Four groundwater boreholes will be installed and soil samples will be collected via push tube from surface, 0.5 m, 1 m and every metre after. In summary, the soil investigation will include: - Ten hand augers - Four groundwater boreholes Waste soils for the installation of groundwater wells will be collected and stored on-site in drums. Boreholes have been named B_HA01 to B_HA10 and B_MW01 to B_MW04.	Install four groundwater wells to a maximum depth of 3 m. The groundwater monitoring wells will be developed initially using mechanical surging techniques; groundwater will be collected and stored on-site in drums. GHD will sample and analyse groundwater samples collected from each of four newly installed wells and one existing well (MW021). In summary, the groundwater investigation will include: - Four new wells - One existing well	Collection of three sediment and surface water samples from the roadside drainage lines that lead into the headwaters of Mary Creek. Sampling locations have been named B_SW01 to B_SW03.	None

Location	Soil program	Groundwater program	Sediment and surface water program	Biota Sampling
AEC C – Former fire training area	*Initial sampling event:* Soil sampling will be conducted from 10 hand auger locations (grid) and six groundwater boreholes across the former firefighting training area to a maximum depth of one metre. Soil samples will be collected at surface, 0.5 m and 1 m. *Second sampling event* An additional nine hand augers, one soil borehole and one groundwater borehole are to be drilled during a second mobilisation to provide delineation of source area impacts. Across the two events, five concrete samples are to be collected from selected locations within the hardstand to test for the impacts and leachability of the concrete capping. In summary, the soil investigation will include: - 19 hand auger boreholes - 1 soil borehole - 7 groundwater boreholes - 5 concrete samples Waste soils for the installation of groundwater wells will be collected and stored on-site in drums. - Boreholes have been named C_HA01 to C_HA19, C_BH01 and C_MW01 to C_MW07.	Install seven new wells to a maximum depth of three metres. The groundwater monitoring wells will be developed initially using mechanical surging techniques; groundwater will be collected and stored on-site in drums. GHD will sample and analyse groundwater samples collected from each of the seven newly installed wells and three existing wells (C_MW028, C_MW029 and C_MW030). In summary, the groundwater investigation will include: - Seven new wells - Three existing wells	See pathway characterisation	None
AEC D – Former building	Soil sampling will be conducted from three hand auger locations triangulated around the footing of the former building to a maximum depth of one metre. Soil samples will be collected at surface, 0.5 m and 1 m. In summary, the soil investigation will include: - Three hand auger boreholes - Soil boreholes will be named D_HA01 to D_HA03.	None	None	None
AEC H – Drum disposal area (SW0027)	Soil sampling will be conducted from five hand auger locations (grid) across the former drum disposal area to a maximum depth of one metre. Soil samples will be collected at surface, 0.5 m and 1 m. Soil boreholes will be named H_HA01 to H_HA05.	GHD will sample and analyse groundwater samples collected from each of three existing wells (MW025, MW026, MW027). In summary, the groundwater investigation will include: - Three existing wells	Collection of three sediment and surface water samples from areas down gradient of the drum disposal area. Sampling locations have been named H_SW01 to H_SW03.	None
HMAS Creswell				
AEC E – Golf Course (SW0035)	Soil sampling will be conducted from 15 hand auger locations (grid) across the golf course to a maximum depth of 1 m. Soil samples will be collected at surface, 0.5 m and 1 m. Drilling of five groundwater wells will be conducted. Soil samples will be collected via direct push methodology to allow for collection of undisturbed samples at surface, 0.5 m, 1 m, and every metre after. In summary, the soil investigation will include: - 15 hand auger boreholes - five groundwater boreholes Waste soils for the installation of groundwater wells will be collected and stored on-site in drums. Boreholes have been named E_HA01 to E_HA15 and E_MW01 and E_MW05.	Install five new wells to a maximum depth of 3 m. The groundwater monitoring wells will be developed initially using mechanical surging techniques; groundwater will be collected and stored on-site in drums. GHD will sample and analyse groundwater samples collected from each of five newly installed wells and two existing wells (MW017 and MW037). Upgradient well MW037 will also be sampled as part of AEC F. In summary, the groundwater investigation will include: - Five new wells - Two existing wells	Collection of four sediment and surface water samples from the retention pond. Sampling locations have been named E_SW01 to E_SW04.	See receptor characterisation
AEC F – Fire station (SW0040)	Drilling of two groundwater wells will be conducted. Soil samples will be collected via direct push methodology to allow for collection of undisturbed samples at surface, 0.5 m, 1 m, and every metre after. In summary, the soil investigation will include: - two groundwater boreholes - two concrete samples Waste soils for the installation of groundwater wells will be collected and stored on-site in drums. Boreholes have been named F_MW01 and F_MW02.	Install two new wells to a maximum depth of 3 m. The groundwater monitoring wells will be developed initially using mechanical surging techniques; groundwater will be collected and stored on-site in drums. GHD will sample and analyse groundwater samples collected from each of two newly installed wells and one existing well (MW037). In summary, the groundwater investigation will include: - Two new wells - One existing well	Collection of two sediment and surface water samples from the roadside drainage lines in front of the fire station. Sampling locations have been named F_SW01 and F_SW02	None

Location	Soil program	Groundwater program	Sediment and surface water program	Biota Sampling
AEC G – Sewage treatment plant and outfall (SW0217 and SW0226)	None	None	Collection of four sediment and surface water samples from the sewage treatment retention pond and drainage line leading to the outfall point at the mouth of Captains Lagoon. Sampling locations have been named G_SW01 to G_SW04.	None
Pathway characterisation				
JBRF				
Storm water drain in AEC A and AEC B	None	None	Sediment and surface water sampling from five locations along the on-site stormwater drain network connecting AECs A and B. Sampling locations have been named AB_SW01 to AB_SW05.	See receptor characterisation
Mary Creek	None	None	Sediment and surface water sampling from three locations along drainage channels on-site leading to Mary Creek. Sampling locations have been named MC_SW06 to MC_SW08.	See receptor characterisation
Drainage lines on-site – (excluding the area between AEC A and AEC B)	None	None	Collection of six sediment and surface water samples along various drainage channels in JBRF and HMAS Creswell. Sampling locations have been named DC_SW01 to DC_SW06. The proposed sampling locations are draft and pending drainage infrastructure plans from Defence.	None
Site boundary wells	Drilling of eleven groundwater wells will be conducted. Soil samples will be collected via direct push methodology to allow for collection of undisturbed samples at surface, 0.5 m, 1 m, and every metre after until bedrock. Proposed drilling depths and positioning are described in the groundwater cell. In summary, the soil investigation will include: - Eleven groundwater boreholes Waste soils for the installation of groundwater wells will be collected and stored on-site in drums. Boreholes have been named FC_MW01 to FC_MW03, CL_MW01, TC_MW01, LM_MW01, LM_MW02, LW_MW01 and BB_MW01 to BB_MW04.	Install eleven new wells. The groundwater monitoring well will be developed initially using mechanical surging techniques; groundwater will be collected and stored on-site in drums. The new wells will be installed in the following locations: - Two wells (FC_MW01 & FC_MW02) on the perimeter of the site within the catchment of Flat Rock Creek (one replacing missing well MW019); and will be drilled to 8 m bgl. - One well (CL_MW01) will be installed in the location of missing well MW023; and will be drilled to 8 m bgl. - One well (FC_MW03) will be installed in the location of missing well MW035; and will be drilled to 8 m bgl. - New well TC_MW01 on the perimeter of the site with the catchment of Telegraph Creek; will be drilled to 8 m bgl. - New wells LM_MW01, LM_MW02 and LW_MW01 on the perimeter of the site with the catchment of Lake McKenzie and Lake Windermere respectively; and will be drilled to 8 m, 40 m and 40 m bgl, respectively. - New wells BB_MW01 to BB_MW03 on the Bherwerre Barrier west of the site; and will be drilled to 5 m bgl. GHD will sample and analyse groundwater samples collected from the newly installed wells and six existing wells (MW018, MW020, MW021, MW022, MW024 and MW036) (also used in the source assessments). In summary, the groundwater investigation will include: - Twelve new wells - six existing wells Rising and falling head tests in eight representative wells on-site to assess hydraulic characteristics of the aquifer for groundwater modelling. Surveying of the groundwater wells and well gauging (two events - general and after wet weather event) to provide data on hydraulic gradients and aquifer connectivity. Inclusion of eight data loggers to monitor groundwater levels between events.	None	None
HMAS Creswell				

Location	Soil program	Groundwater program	Sediment and surface water program	Biota Sampling
AEC E – STP treated water irrigation system	None	None	Four samples of irrigation water from the sprinklers at the golf course (E_Irrigation_01 to E_Irrigation_04).	None
Captains Lagoon	None	None	Sediment and surface water sampling from 11 locations along Captains Lagoon (two events). Sampling locations have been named CL_SW01 to CL_SW11.	See receptor characterisation
Site boundary wells	Drilling of four groundwater wells will be conducted. Soil samples will be collected via direct push methodology to allow for collection of undisturbed samples at surface, 0.5 m, 1 m, and every metre after. In summary, the soil investigation will include: - four groundwater boreholes Waste soils for the installation of groundwater wells will be collected and stored on-site in drums. Boreholes have been named CL_MW02 to CL_MW05	Install four new wells to a maximum depth of three metres. The groundwater monitoring well will be developed initially using mechanical surging techniques; groundwater will be collected and stored on-site in drums. GHD will sample and analyse groundwater samples collected from the newly installed wells and two existing wells (MW001 and MW008) (Figure 7J). In summary, the groundwater investigation will include (two events): - Four new wells - Two existing wells Rising and falling head tests in four representative wells on-site to assess hydraulic characteristics of the aquifer for groundwater modelling. Surveying of the groundwater wells and well gauging (two events - general and after wet weather event) to provide data on hydraulic gradients and aquifer connectivity. Inclusion of four data loggers to monitor groundwater levels between events.	None	None
Both sites: STP system investigation	None	None	Surface water sampling at nine locations (eight on the main pipe network and one at Wreck Bay septic tank) on three occasions (one during peak use, one off peak (overnight) and one after wet weather). There is an allowance for an additional four samples from additional branches of the network (if required). Sampling locations will be named STP01 to STP09 (STP10 to STP14 (if required)).	None
Receptor characterisation				
Groundwater off-site points	Soil sampling will be conducted from four groundwater borehole to a maximum depth of one metre. Soil samples will be collected at surface, 0.5 m and 1 m. Four concrete cores are to be collected from selected locations within the hardstand to test for the impacts and leachability of the concrete capping. In summary, the soil investigation will include: - 4 groundwater boreholes - 4 concrete cores Waste soils for the installation of groundwater wells will be collected and stored on JBRF site in drums. Boreholes have been named MC_MW01 to MC_MW04.	Sampling of additional (up to) 10 off-site wells (at points of use) to close data gaps. Locations are yet to be confirmed (POU_01 to POU_10), and four ACT government wells (Kullindi Homestead, Christian's Minde, Bay of Plenty and Rail Bus Tram Union) (two events). Install four new wells in the Wreck Bay Village to a maximum depth of maximum depth of 10 metres (MC_MW01 to MC_MW04). The groundwater monitoring well will be developed initially using mechanical surging techniques; groundwater will be collected and stored on JBRF in drums. GHD will sample and analyse groundwater samples collected from the newly installed wells on two occasions. In summary, the groundwater investigation will include: - Four new wells - 14 existing wells	None	None

Location	Soil program	Groundwater program	Sediment and surface water program	Biota Sampling
Potable water sources	None	None	Sediment and surface water sampling from nine locations in Lake Windermere, Lake McKenzie and three above ground water tanks to the east of JBRF (one per tank) and raw water inlet to the treatment plant (two events). Sampling locations have been named LW_SW01 to LW_SW05, LM_SW_01 to LM_SW04 and AST_SW01 to AST_SW03, raw water in (Raw_SW04),	One location at Lake McKenzie (comparable habitat to Lake Windermere) will be sampled for macrophytes (roots), invertebrates (yabbies, molluscs, insects, etc.), and fish. One terrestrial location will be sampled for vegetation (grasses, roots, fruits, etc.), and invertebrates (insects, worms, gastropods, etc.).
Telegraph Creek – two surface water channels and a Green Patch lagoon and spring	None	None	Sediment and surface water sampling from ten locations (two events). Sampling locations have been named TC_SW01 to TC_SW09 and UN4_SW01. Two sediment and surface water samples between end of creek to furthest point into Jervis Bay accessible at low tide, collected at sediment/water interface. Sample locations have been named TC_SW10 to TC_SW11. One sample of marine water from Jervis Bay, sample to be named JB_SW03. Sampling will be conducted on two occasions.	None
Mary Creek, Summercloud Creek and unnamed creek and lagoon, springs	A complementary soil sample will be collected from each terrestrial sample location.	None	Sediment and surface water sampling from 16 locations (two events). Sampling locations have been named MC_SW01 to MC_SW05, SC_SW01 to SC_SW04, UN1_SW01 and UN1_SW02, UN2_SW01 to UN2_SW05. Seven seepage /spring locations, bathing holes around Wreck Bay village sample locations have been named UN3_SW01 to UN3_SW07 (two occasions). Two sediment and surface water samples between end of each creek to furthest point into Jervis Bay accessible at low tide, collected at sediment/water interface. Sample locations have been named UN_SW03 to UN_SW04, MC_SW05 and MC_SW06 and SC_SW05 and SC_SW06. Three sample of marine water from Wreck Bay, sample to be named WB_SW01 to WB_SW03. Sampling will be conducted on two occasions.	Two freshwater and one estuarine location along Mary Creek will be sampled for macrophytes (roots), invertebrates (yabbies, molluscs, insects, etc.), and fish. One freshwater and one estuarine location will be sampled along Summercloud Creek for macrophytes (roots), invertebrates (yabbies, molluscs, insects, etc.), and fish. One unnamed freshwater pool will be sampled for for macrophytes (roots), invertebrates (yabbies, molluscs, insects, etc.), and fish, as available. Two terrestrial locations will be sampled for vegetation (grasses, roots, fruits, etc.), invertebrates (insects, worms, gastropods, etc.), and vertebrates (roadkill, as available).
Wreck Bay	None	None	A surface water and sediment sample will be collected from each biota sampling location.	One marine location will be sampled for macroalgae and other aquatic plants, invertebrates (crustaceans, echinoderms, oysters, cephalopods, etc.), and fish.
Flat Rock Creek – connection with Jervis Bay	None	None	Two sediment and surface water samples between end of creek to furthest point into Jervis Bay accessible at low tide, collected at sediment/water interface. Sample locations have been named FC_SW14 to FC_SW15. One sample of marine water from Jervis Bay, sample to be named JB_SW01. Sampling will be conducted on two occasions.	One freshwater and two estuarine locations along Flat Rock Creek will be sampled for macrophytes (roots), invertebrates (yabbies, molluscs, insects, etc.), and fish.

Location	Soil program	Groundwater program	Sediment and surface water program	Biota Sampling
Captains Lagoon – connection with Jervis Bay	A complementary soil sample will be collected from each terrestrial sample location.	None	Two sediment and surface water samples between end of creek to furthest point into Jervis Bay accessible at low tide, collected at sediment/water interface. Sample locations have been named CL_SW12 to CL_SW13. One sample of marine water from Jervis Bay, sample to be named JB_SW02. Sampling will be conducted on two occasions.	Two freshwater and one estuarine location along Captains Lagoon will be sampled for macrophytes (roots), invertebrates (yabbies, molluscs, insects, etc.), and fish. One terrestrial location will be sampled for vegetation (grasses, roots, fruits, etc.) and invertebrates (insects, worms, gastropods, etc.).
Jervis Bay	None	None	A surface water and sediment sample will be collected from each biota sampling location.	Three marine locations (one of which serving as a control) will be sampled for macroalgae and other marine plants, invertebrates (crustaceans, echinoderms, oysters, cephalopods, etc.), and fish.
JBRF	A complementary soil sample will be collected from each terrestrial sample location.	None	None	Two terrestrial locations will be sampled for plants and invertebrates (insects, worms, gastropods, etc.). Approximately four roadkill samples are expected to be collected near the boundary to the north of JBRF.
HMAS Creswell	A complementary soil sample will be collected from each terrestrial sample location.	None	None	Two terrestrial locations will be sampled for plants and invertebrates (insects, worms, gastropods, etc.). Approximately four samples of kangaroo or wallaby that die of natural causes near to AEC E are expected.
Resident Vegetable Gardens	One complementary soil sample from each garden where produce is collected will be analysed.	None	None	Edible portions of legumes, leafy vegetables, and fruit (including citrus) will be sampled from up to three gardens.

3.3 Data quality and evaluation

The quality assurance/quality control (QA/QC) procedures are based on *ASC NEPM* (NEPC 2013) and DER *Assessment and management of contaminated sites* (DER 2014). The QA/QC procedures are outlined in detail in the SAQP (GHD 2017a).

GHD developed a set of Data Quality Objectives (DQOs) as part of the SAQP (GHD 2017a), with reference to Schedule B2 of the NEPC (2013) guidelines. The purpose of the DQOs is to define the type, quantity and quality of data to be collected and inform decisions relating to the contamination status of the site.

All data obtained during the DSI will undergo a review and validation process to ensure that the dataset is of optimal integrity with reference to the Data Quality Indicators (DQIs) namely; completeness, comparability, representativeness, precision and accuracy. Only data which is assessed as valid in terms of the DQIs will be used as inputs to the HHERA.

4. HHRA approach

4.1 Overview

As outlined in Section 1.4, assessment of human health risk will be undertaken in accordance with the approach outlined in Schedules B4 and B7 of NEPC (2013). This approach is summarised in Figure 5 below while the key steps are described in Sections 4.2 to 4.5.

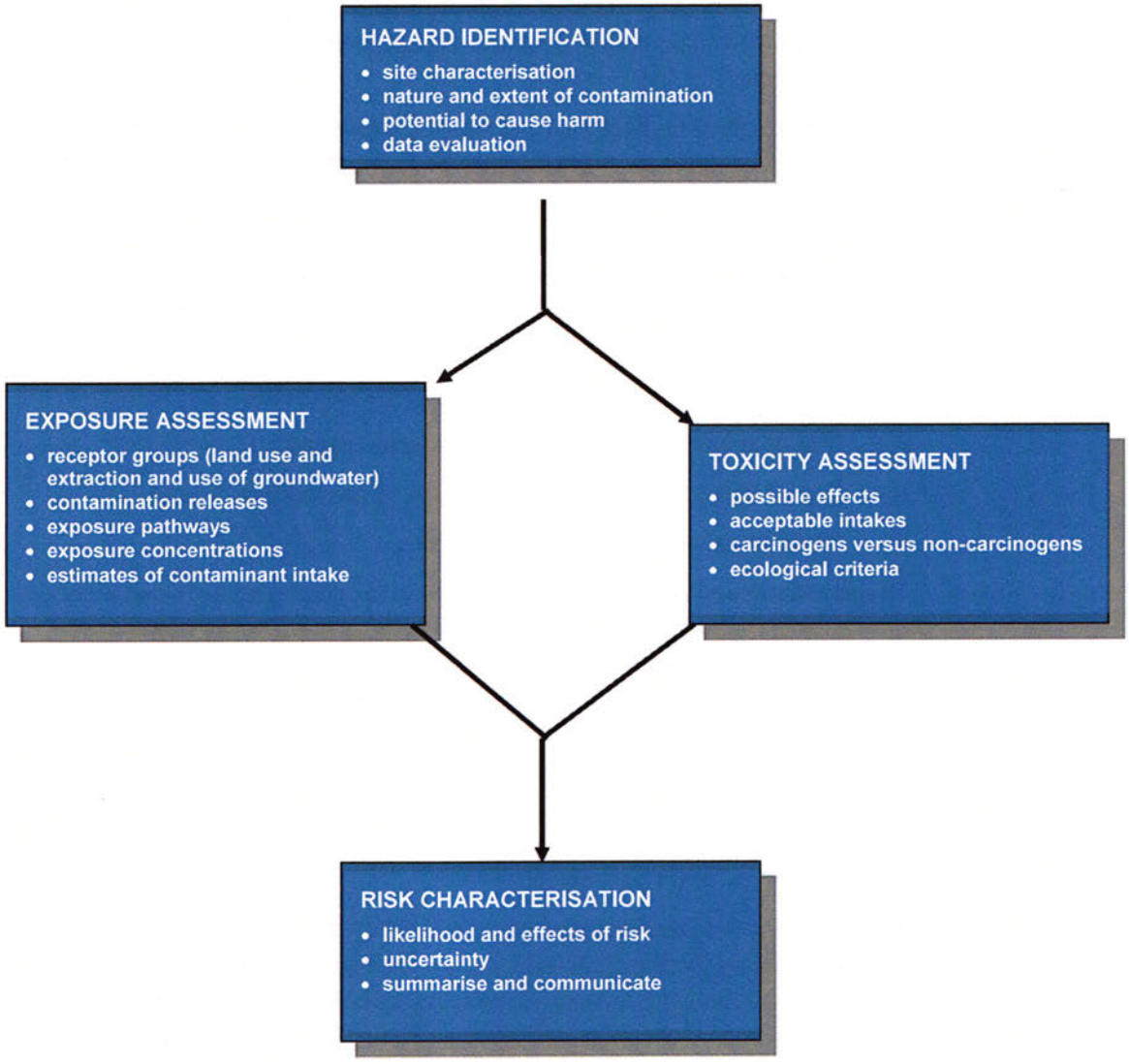

Figure 5 HHRA approach (NEPM 2013, EnHealth 2012)

4.2 Hazard identification

Hazard identification involves a review of the results of the investigations conducted to establish:

- The key contaminants of concern;
- The extent and magnitude of contamination present at the site; and
- The health concerns or issues that the risk assessment needs to address.

A robust and complete CSM is critical to the hazard identification step. The CSM, based on GHD's current understanding of the site conditions, is summarised in Section 2 of this HHERA Plan and Methodology and will be further refined at completion of the DSI and prior to commencement of the HHERA.

4.3 Toxicity assessment

4.3.1 Overview

The purpose of the toxicity assessment is to assess the potential effects of the contaminants of concern (i.e. PFAS) on human health, to determine the levels of exposure that could give rise to adverse effects.

This information will be used together with the exposure assessment (refer to Section 4.4) to assess the risks associated with the identified contamination.

4.3.2 General principles

A toxicity assessment is defined as the process of determining whether human exposure to a chemical could cause an increase in the incidence of an adverse health condition (NEPC, 2013; ANZECC/NHMRC, 1992; USEPA, 1989). It considers:

- The nature of adverse effects related to the exposure;
- The dose-response relationship for various effects;
- The weight of evidence for effects such as carcinogenicity; and
- The relevance of animal data to humans.

The assessment of the toxicity of contaminants of concern is based on published human and animal toxicity information for each of these compounds. The reported adverse effects in humans and animals (associated with exposure to the contaminants of concern) will be reviewed in order to develop an understanding of the types of possible health effects that may result from exposure to these chemicals.

The results of the toxicity assessment are represented by a set of toxicity criteria that are used to help evaluate the risk associated with the contamination at a site.

4.3.3 Dose-response assessment

Human toxicity data (either occupational or epidemiological) are the preferred source of information for evaluating chemical toxicity. However, there is relatively little human health effects data available for most chemicals. In the absence of adequate human data, the results of toxicity studies in laboratory animals are used and extrapolated for humans. These studies are designed to identify what adverse effects may result following prolonged exposure to a chemical, and at what exposure level these effects are observed. When animal data are evaluated, consideration is given to the study design and the suitability of the animal studies to human exposure settings. Extrapolation from animal data is commonly used to determine acceptable exposure levels for humans.

The development of acceptable human health exposure levels is deliberately conservative. Studies that identify exposure levels associated with no effects (often termed the "no observable adverse effects level" [NOAEL]) are typically the basis for human toxicity criteria. A series of uncertainty factors (also known as safety factors) are applied to the NOAEL value to convert the results of the animal study into a human health protective value.

The end result of this process is a human health toxicity value designed to protect against any adverse effects associated with exposure to a particular chemical. Regulatory agencies such as

the Food Standards Australia and New Zealand (FSANZ), the World Health Organisation (WHO) and United States Environmental Protection Agency (USEPA) are the primary sources of the toxicity criteria for most chemicals. In particular, the draft criteria released by the Office of Environment and Heritage (OEH) (refer to Section 4.3.4) will be considered.

4.3.4 Toxicity criteria

Chemical-specific toxicity criteria will be selected for PFAS based upon the recommendations provided predominantly by FSANZ, and supplemented by OEH in their interim guidance statement *OEH Science: PFAS Screening Criteria* (OEH, 2017) and DCD #8 (2015, and Amendments 1 (2016) and 2 (2017). A summary of the toxicological endpoints will also be provided.

It is noted that FSANZ (2016 and 2017) and OEH (2017) only provide guideline screening values for three PFAS chemicals, as summarised in Table 5.

Table 5 Interim human health guidance values for PFAS

Guidance value	PFOS/PFHxS	PFOA	6:2 FTS
Tolerable daily intake (µg/kg/d)[ab]	0.02	0.16	--
Drinking water quality guideline (µg/L)[ab]	0.07	0.56	5.0[d]
Recreational water quality guideline (µg/L)[ab]	0.7	5.6	50[d]
Finfish, crustacean & molluscs (µg/kg biota ww)[a]	5.2	41	--
Soil: residential (mg/kg)[a]	0.009	0.1	--
Soil: human health – residential (direct contact only) (mg/kg)[d]	6	16	60
Soil: human health – industrial (direct contact only) (mg/kg)[e]	90	240	900
Milk (µg/kg)[c]	0.4	2.8	--
Honey (µg/kg)[c]	33	264	--
Fruit (µg/kg)[c]	0.6	5.1	--
Vegetables (µg/kg)[c]	1.1	8.8	--
Poultry Eggs (µg/kg)[c]	11	85	--
Offal Mammalian (µg/kg)[c]	96	765	--
Meat Mammalian (µg/kg)[c]	3.5	28	--

Notes:

[a] – Office of Environmental Health (OEH) Interim Human Health Reference Values (2017)

[b] – Food Standards Australia New Zealand (FSANZ) Health Based Guidance Values for PFAS (2017)

[c] – Food Standards Australia New Zealand (FSANZ) Proposed Trigger Points (2016)

[d] – Defence Contamination Directive (DCD) #8 Interim Screening Criteria (Amendment 1) (2016)

[e] – Defence Contamination Directive (DCD) #8 Interim Screening Criteria (2015)

Given that the contamination is from historical use of AFFF, it is anticipated that these three chemicals will make up more than 90% of the source concentration/mass. In this case, there is no requirement to assess quantitatively the other components of PFAS in the HHERA.

However, should sampling results indicate PFAS other than the primary three compounds contribute a more significant component (>10% of total), then the relative toxicity of these components will be assessed. If the >10 % figure is achieved GHD will apply TEFs to other PFAS chemicals as a conservative factor. Consideration will be given to toxicity reference values presented in guidelines published by international agencies, such as the TCEQ in order to derive TEQ for other PFAS compounds.

4.3.5 Background exposure

Background exposure refers to exposure of populations to chemical concentrations which may be present in the environment as a result of everyday activities or natural sources. As per enHealth (2012) guidance, background exposure will be considered in the risk assessment. In this respect, discussion can be presented on background exposure of PFAS by Australians, and the contribution to the toxicity reference values these present. Background exposure to PFAS will be taken from the study presented in the CRC Care Guidance (2017a) used to derive PFAS Health Screening Levels (HSLs).

4.4 Exposure assessment

The exposure assessment documents the selection of potentially exposed populations and exposure pathways used in estimating the potential health and environmental risks arising from exposure to the COPCs. The CSM, as summarised in Section 2, forms the basis of the detailed exposure assessment.

4.4.1 Exposure parameters

In the absence of direct measurements relating to exposures of affected populations, exposure parameters will be assumed based upon the recommendations presented in NEPC (2013) and enHealth (2012), and from information provided by local residents in the water use and biota survey. The key elements to be identified include:

- Input values for contaminant concentrations and pathways,
- Input values for exposed populations,
- Estimated exposure concentrations, and
- Estimated chemical intake.

Preliminary exposure parameters have been defined for human receptors, including adult and child residents at Wreck Bay Village and Jervis Bay Village, on-site JBRF base personnel, HMAS Creswell maintenance workers, and adult and child recreational users of both Wreck Bay and Jervis Bay (and surrounding freshwater inlets). It should be noted that these exposure parameters are based upon assumptions and information currently received from the communities present, as well as National guidance, however, these values may need to be amended following additional correspondence and input from the communities. The preliminary exposure parameters are presented in Appendix B. Some of the assumptions presented in Appendix B are based upon the results from the Community Survey. As such, the results from the Community Survey are presented in Appendix C.

4.4.2 Exposure point concentrations

Exposure point concentrations will be based upon the chemical concentrations measured within the various media sampled, at the point of exposure. As a conservative measure, exposure

concentrations will initially be selected based on the maximum measured concentrations which may be encountered by each identified receptor.

4.4.3 Estimation of chemical intakes

Exposure will be calculated using the equations presented in Schedule B4 and B7 of NEPC (2013). The relevant algorithms will be included within the HHERA report.

For soil exposure, exposure calculations will be undertaken for on-site commercial / industrial workers, utility maintenance workers involved in excavation works, and for residents in residential areas where surface soil contamination is identified. Exposure to dust particles also contributes to exposure through direct contact with contaminated soil. However, this can be shown to contribute less than 1% of the dose through oral and dermal exposure from soil.

Based upon the water use survey provided to residents of Jervis Bay Village and Wreck Bay Village, clay was commonly used topically (i.e., as a sunscreen), or occasionally ingested by pregnant women when they had cravings. As such, dermal absorption and ingestion of affected clay will be considered in the HHRA.

Exposure during irrigation (such as the reuse water at the golf course) will consider inhalation and incidental ingestion of aerosol spray as well as dermal absorption (through skin).

Exposure through domestic use and recreational use of surface water to residents and recreational users of affected areas. Exposure will be considered against the criteria listed in Table 5.

Consideration will also be given to consumption of produce and biota that is proposed to be sampled during the DSI. If detected within produce and biota, site-specific exposure and risk calculations will be undertaken. Exposure parameters such as produce ingestion rates will consider information supplied by the community in the water use and biota survey, as well as generalised information from the Australian Bureau of Statistics. Relevant biota to the local community includes a wide variety of both freshwater and marine invertebrates and fish such as yabbies, pippies, periwinkles, whiting, lobsters, flathead, bream, mullet, and bait fishes. Terrestrial flora such as geebungs, berries, lilli pillies, pigface, passionfruit, sarsaparilla, and Five Corners were reported to be consumed from all around JBT.

While fauna was reportedly no longer consumed from JBT, the cultural significance of consuming larger terrestrial fauna such as kangaroo, possum, rabbit, and birds remains. As such, consumption of terrestrial fauna will be considered in the HHRA to approximate exposure if fauna were to be consumed again in the future.

No use of domestic stock has been reported at the location (i.e., chickens [eggs or meat] or cattle [milk or meat]), however these pathways would be considered in future iterations of the HHRA should they be identified.

Consumption of breast milk by infants will be considered.

4.5 Risk characterisation

The purpose of the risk characterisation is to combine the results of the toxicity assessment (i.e. the potential for health effects) with the predicted exposures to determine whether the COPCs pose an unacceptable health risk, and therefore what measures need to be taken to reduce the risk. The risk characterisation section will include:

- Summary of investigation (sampling data and corresponding risk and relevant exposure pathways); and
- Discussion of uncertainties, data gaps, key assumptions and limitations.

4.5.1 Hazard quotient

Non-carcinogenic health effects may be assessed by direct comparison of the exposure concentration with the Reference Concentration (RfC) or Chronic Daily Intake (CDI) with the Adjusted Tolerable Daily Intake (TDI). Note the TDI is based on a long-term steady state intake rate.

A hazard quotient (HQ) less than 1 indicates that adverse health effects resulting from that particular chemical and exposure route are not likely to occur.

The Hazard Index (HI) is defined as the sum of the HQs for each exposure route. This HI determination considers cumulative exposure to PFAS from applicable pathways to each receptor. A HI of less than 1 indicates that adverse health effects are not likely to occur. A HI of greater than 1 does not indicate that adverse health effects are necessarily expected to occur, rather than a more detailed study of the potential risks should be conducted.

Due to the complexity of the site, including the number of receptors and potentially affected locations, it is assumed in the risk calculations that Wreck Bay residents will be recreational users of Wreck Bay only, and that Jervis Bay residents will be recreational users of Jervis Bay only. While this may be an oversimplification of the likely land use in the area, conducting the calculations in this manner will provide an overall conservative estimate of potential exposure to the Wreck Bay community in particular, where PFAS contamination may be more widespread and at higher concentrations based upon the data received to date.

Cumulative exposures will be considered for Jervis Bay residents and recreational users (adult and child), Wreck Bay residents and recreational users (adult and child), Booderee National Park workers and Wreck Bay recreational users (adult), JBRF personnel and Jervis Bay recreational users (adult), and HMAS Creswell Maintenance Workers and Jervis Bay recreational users (adult).

For the purpose of this risk assessment, the HI for exposure to PFAS contamination should be less than 1.

Based on the findings of the risk assessment, uncertainties and risk management options will be discussed.

4.5.2 Sensitivity assessment

Risk assessments involve a number of assumptions regarding site conditions, human exposure and chemical toxicity. Even though the estimates will draw on site-specific information (e.g. geotechnical and analytical data), it is not possible to fully describe site conditions and human activities at a site for the period of time considered in the risk assessment. The assumptions adopted for the risk assessment can be expected to be generally conservative in nature, to account for uncertainty in the parameter estimates and to protect public health by providing a deliberate margin of safety.

A qualitative evaluation of the sensitivity of the risk assessment to particular assumptions will be included within the report, including assumptions in relation to:

- Contaminants of concern,
- Toxicity criteria, and
- Exposure assumptions.

5. ERA approach

5.1 Overview

As outlined in Section 1.4, GHD will perform an initial preliminary ERA following the approach outlined in NEPC (2013) Schedule B5a, a summary of which is shown in Figure 6 below. This approach takes into account the following aspects:

- Identification of the ecological receptors of concern;
- Estimation of the concentrations of the contaminants of concern to which the ecological receptors may be exposed;
- Consideration of any toxicity modifying or toxicity enhancing capacity of the receiving environment;
- Determination if ecological receptors may be at risk; and
- Application of a multiple lines of evidence approach to assess risk.

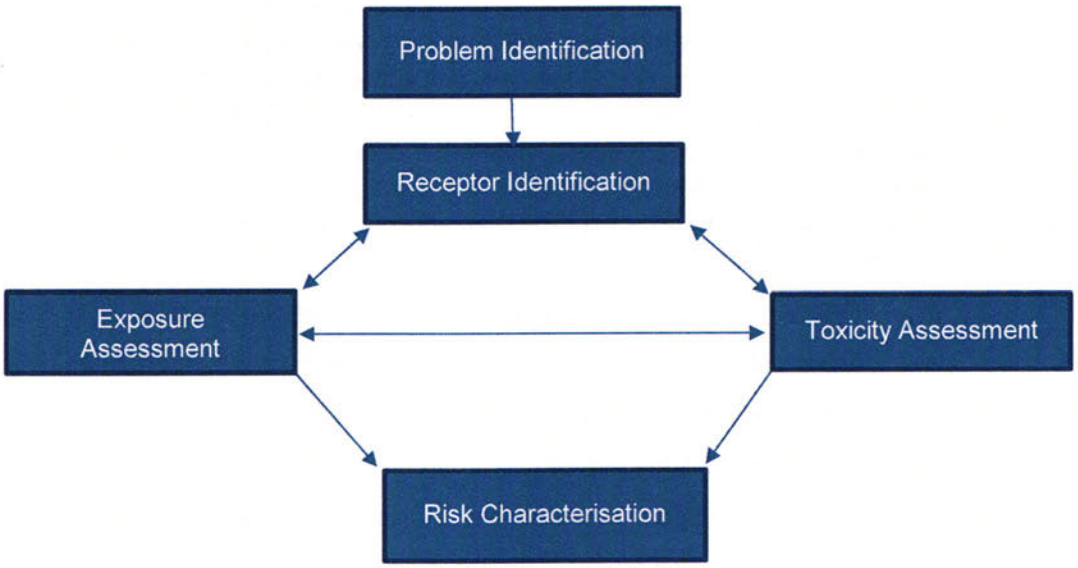

Figure 6 ERA approach (NEPC 2013)

5.2 Problem identification

This stage of the ERA establishes the objectives and identifies the data required to achieve those objectives. Stakeholder consultation has commenced and is on-going so that the community has opportunities to become involved in the assessment process and identify their concerns.

5.3 Receptor identification

Terrestrial and aquatic receptor identification requires the identification of local species, communities and ecological processes that are of ecological value. The ecological values are based on societal, cultural, ecological and economic factors as identified during the stakeholder consultation process. Based on this process the stakeholders are made aware of the concept of acceptable risk to the ecological values that need to be protected. During the sampling activities proposed in the SAQP (GHD 2017a), ecological surveys will be conducted to confirm relevant ecological receptors in the area to support the desktop ecological assessment.

Contamination sources and pathways have been identified in the CSM report (GHD 2017a) and are summarised in Section 2.

The identified ecological receptors may be exposed through one or more of the following exposure pathways:

- direct contact and uptake of:
  - Soil,
  - Surface water and sediments (including pore water),
  - Groundwater; and
- Consumption of flora and fauna already affected from exposure to contaminated soil, groundwater, sediment and/or surface water.

5.3.1 On-site receptors

Although approximately 21% of HMAS Creswell and 33% of JBRF are maintained areas, the remaining area on site consists of forest/woodland (55% and 13% for HMAS Creswell and JBRF, respectively), dry heath/scrubland (9% and 46%, respectively), and wet heath/sedgeland (11% and 8%, respectively). Wetlands and ponds account for the remaining 3% of HMAS Creswell (SKM 2006). Ten Threatened Ecological Communities (TECs) are known or predicted to exist within 10 km of JBRF, and 10 threatened flora species and 100 threatened fauna species are known or expected to be present within 5 km of JBRF. JBRF is unique from other Defence sites as there is an abundance of biota and habitats surrounding the site. This biological diversity and complexity means there are myriad potential receptors for PFAS, and a wide breadth of samples are required to minimize assumptions regarding PFAS accumulation. Given the ability of PFOS and PFOA to bioaccumulate, the levels of these compounds in animal tissue increases at each stage of the food chain.

- Plants including grasses, roots, or fruits, which are consumed by higher order species;
- Lower order animals such as earthworms, insects, or gastropods; and
- Higher order animals such as birds, fish, rabbits and native marsupials.

Other ecological receptors include:

- The superficial groundwater aquifer and associated biota e.g. stygofauna; and
- Surface water bodies (including Flat Rock Creek and Captains Lagoon) and associated biota receiving surface water runoff from the site.

5.3.2 Off-site receptors

Potential off-site receptors include:

- Plants and animals as described for on-site receptors above, including:
  - Home grown produce;
  - Plants including grasses, roots, fruits, or algae, which are consumed by higher order species;
  - Lower order animals such as earthworms, insects, molluscs, or crustaceans; and
  - Higher order animals such as birds, fish, or mammals;
- The receiving surface water bodies down-gradient of the site, notably, Mary Creek, Wreck Bay, Flat Rock Creek, Captains Lagoon, Jervis Bay, and potentially Telegraph Creek, Summercloud Creek, a series of unnamed creeks, or Lake McKenzie or Lake Windermere;

- Booderee National Park surrounding JBRF that could potentially be affected by airborne transport, groundwater, runoff or surface water.

The results of the current monitoring program will be used to confirm the type of receptors and impact to the receptors from exposure to the contamination levels.

5.3.3 Selected receptor groups

For the purpose of the ERA, ecological receptor groups have been selected to represent relevant classes of receptors known or expected to be present at the site. It is not feasible to consider exposure to all ecological receptors present. The selected trophic levels encompass species assemblages with similar feeding preferences. For each trophic level, representative species (indicator species) are selected for the purpose of exposure assessment modeling. Amphibians will not be considered in the quantitative ERA evaluation due to the general paucity of toxicological and exposure parameter data. The existing literature is also sparse for consideration of reptiles. However, impacts to reptiles and amphibians will be evaluated semi-quantitatively, as available literature and assumptions allow.

Generally, indicator species have been selected based upon representativeness of the trophic level and encompassing varying organism sizes, the availability of information in the literature regarding home ranges and daily dietary intake, and relevance to the locations (i.e., recent observations). GHD notes that these selected species are preliminary, and may be subject to change pending species observations in the field, and/or selection of representative organisms with additional information in the literature. Preliminary species selected for consideration in the ERA are presented in Table 6.

Table 6 Preliminary representative species selection for consideration in the ERA

Trophic Level	Indicator Species	Justification	Site Specific Sampling Inputs
Terrestrial			
Terrestrial plants	Various	Terrestrial plants such as grasses, fruits, and flowers will be targeted to consider uptake in a range of flora consumed by ecological (and/or human) receptors.	Seven locations (five high priority locations) are proposed for sampling of ecologically relevant terrestrial flora. Per the SAQP (GHD, 2017), it is proposed that five samples of each of four flora species will be collected from each location.
Terrestrial invertebrates	Various	Terrestrial invertebrates such as insects, gastropods and worms will be targeted to consider uptake to a range of ecological receptors.	Seven locations (five high priority locations) are proposed for sampling of ecologically relevant terrestrial invertebrates. Per the SAQP (GHD, 2017), it is proposed that five samples of each of up to six functional feeding groups (including flying insects, worms, gastropods, bees, ants and spiders) will be collected from each location.
Insectivorous / omnivorous reptiles	Copper tailed skink	Biomagnification may occur within this trophic level, and as such, will be considered in the ERA.	Due to difficult sampling requirements and limited literature regarding the relationships between reptile blood and tissue concentrations of PFAS, sampling for reptiles will not be conducted. Rather, concentrations will be calculated using semi-quantitative food-web modelling.
Carnivorous reptile	Jacky Lizard Red-bellied black snake	Biomagnification may occur within this trophic level, and as such, will be considered in the ERA.	Due to difficult sampling requirements and limited literature regarding the relationships between reptile blood and tissue concentrations of PFAS, sampling for reptiles will not be conducted. Rather, concentrations will be calculated using semi-quantitative food-web modelling.
Avian herbivores	Australian King Parrot	Biomagnification may occur within this trophic level, and as such, will be considered in the ERA.	Direct sampling is not proposed for avian consumers, however PFAS exposure will be addressed using semi-quantitative food-web modelling.
Avian insectivores / omnivores	Golden Whistler White-throated Treecreeper	Biomagnification may occur within this trophic level, and as such, will be considered in the ERA.	Direct sampling is not proposed for avian consumers, however PFAS exposure will be addressed using semi-quantitative food-web modelling.
Avian carnivores	Pied Butcherbird Laughing Kookaburra Square-tailed kite	Biomagnification may occur within this trophic level, and as such, will be considered in the ERA.	Direct sampling is not proposed for avian consumers, however PFAS exposure will be addressed using semi-quantitative food-web modelling.
Mammalian herbivores	Grey-headed Flying Fox Swamp Wallaby Eastern Grey Kangaroo	Biomagnification may occur within this trophic level, and as such, will be considered in the ERA.	Direct sampling is proposed for mammals via roadkill opportunities, if feasible. This data will be used in tandem with semi-quantitative food-web modelling to approximate PFAS exposure to this trophic level.
Mammalian insectivores	Gould's Wattled Bat Short-beaked echidna	Biomagnification may occur within this trophic level, and as such, will be considered in the ERA.	Direct sampling is proposed for mammals via roadkill opportunities, if feasible. This data will be used in tandem with semi-quantitative food-web modelling to approximate PFAS exposure to this trophic level.
Mammalian omnivores	Sugar glider Southern brown bandicoot	Biomagnification may occur within this trophic level, and as such, will be considered in the ERA.	Direct sampling is proposed for mammals via roadkill opportunities, if feasible. This data will be used in tandem with semi-quantitative food-web modelling to approximate PFAS exposure to this trophic level.
Mammalian carnivores	Spotted-tailed quoll Fox	Biomagnification may occur within this trophic level, and as such, will be considered in the ERA.	Direct sampling is proposed for mammals via roadkill opportunities, if feasible. This data will be used in tandem with semi-quantitative food-web modelling to approximate PFAS exposure to this trophic level.

Trophic Level	Indicator Species	Justification	Site Specific Sampling Inputs
Freshwater			
Aquatic plants and algae	Various	Aquatic freshwater plants growing on the surface of waterbodies or immersed within the water column will be targeted to consider uptake in a range of ecologically relevant flora.	Eight locations (five high priority locations) are proposed for sampling of ecologically relevant freshwater flora. Per the SAQP (GHD, 2017), it is proposed that five samples of each of two flora species will be collected from each location.
Herbivorous / omnivorous invertebrates	Various	Freshwater invertebrates such as insects, gastropods, molluscs and crustaceans will be targeted to consider uptake to a range of ecological receptors.	Eight locations (five high priority locations) are proposed for sampling of ecologically relevant freshwater invertebrates. Per the SAQP (GHD, 2017), it is proposed that five samples of each of up to three functional feeding groups (insects, gastropods, molluscs or crustaceans) will be collected from each location. Yabbies will be targeted, with two distinct samples taken; edible tail tissue and whole organism.
Insectivorous / omnivorous amphibians	Jervis Bay Tree Frog Common eastern froglet	Biomagnification may occur within this trophic level, and as such, will be considered in the ERA.	Due to difficult sampling requirements and limited literature regarding the relationships between amphibian blood and tissue concentrations of PFAS, sampling for amphibians will not be conducted. Rather, concentrations will be calculated using semi-quantitative food-web modelling, pending relevant literature.
Insectivorous / omnivorous reptile	Eastern water skink	Biomagnification may occur within this trophic level, and as such, will be considered in the ERA.	Due to difficult sampling requirements and limited literature regarding the relationships between reptile blood and tissue concentrations of PFAS, sampling for reptiles will not be conducted. Rather, concentrations will be calculated using semi-quantitative food-web modelling.
Carnivorous reptile	Eastern Snake-necked turtle Tiger Snake	Biomagnification may occur within this trophic level, and as such, will be considered in the ERA.	Due to difficult sampling requirements and limited literature regarding the relationships between reptile blood and tissue concentrations of PFAS, sampling for reptiles will not be conducted. Rather, concentrations will be calculated using semi-quantitative food-web modelling.
Avian herbivores	Australian Wood Duck Black Swan	Biomagnification may occur within this trophic level, and as such, will be considered in the ERA.	Direct sampling is not proposed for avian consumers, however PFAS exposure will be addressed using semi-quantitative food-web modelling.
Avian insectivores / omnivores	Masked Lapwing Pacific Black Duck Australasian Swamphen	Biomagnification may occur within this trophic level, and as such, will be considered in the ERA.	Direct sampling is not proposed for avian consumers, however PFAS exposure will be addressed using semi-quantitative food-web modelling.
Avian carnivores	Azure Kingfisher Little Black Cormorant White-bellied Sea-Eagle	Biomagnification may occur within this trophic level, and as such, will be considered in the ERA.	Direct sampling is not proposed for avian consumers, however PFAS exposure will be addressed using semi-quantitative food-web modelling.
Omnivorous fish	Empire gudgeon Black Drummer	Biomagnification may occur within this trophic level, and as such, will be considered in the ERA.	Eight locations (five high priority locations) are proposed for sampling of ecologically relevant freshwater fish. Per the SAQP (GHD, 2017), it is proposed that five samples of each of three fish species will be collected from each location. Pending organism size, two distinct samples are proposed for each fish; edible fillet and whole organism.
Carnivorous fish	Marbled eel	Biomagnification may occur within this trophic level, and as such, will be considered in the ERA.	Eight locations (five high priority locations) are proposed for sampling of ecologically relevant freshwater fish. Per the SAQP (GHD, 2017), it is proposed that five samples of each of three fish species will be collected from each location. Pending organism size, two distinct samples are proposed for each fish; edible fillet and whole organism.
Estuarine/Marine			
Aquatic plants and algae	Various	Estuarine/marine plants and algae growing are targeted to consider uptake in a range of ecologically relevant flora.	Nine locations (seven high priority locations) are proposed for sampling of ecologically relevant marine flora. Per the SAQP (GHD, 2017), it is proposed that five samples of each of two flora species will be collected from each location.

Trophic Level	Indicator Species	Justification	Site Specific Sampling Inputs
Benthic aquatic invertebrates	Various	Benthic estuarine/marine invertebrates such as gastropods, molluscs, echinoderms and crustaceans will be targeted to consider uptake to a range of ecological receptors.	Nine locations (seven high priority locations) are proposed for sampling of ecologically relevant estuarine/marine invertebrates (benthic and pelagic). Per the SAQP (GHD, 2017), it is proposed that five samples of each of up to seven functional feeding groups will be collected from each location. For crustaceans and cephalopods, two distinct samples will be taken; edible tissue and whole organism.
Pelagic aquatic invertebrates	Squid	Pelagic estuarine/marine invertebrates such as cephalopods will be targeted to consider uptake to a range of ecological receptors.	Nine locations (seven high priority locations) are proposed for sampling of ecologically relevant marine invertebrates (benthic and pelagic). Per the SAQP (GHD, 2017), it is proposed that five samples of each of up to seven functional feeding groups will be collected from each location. For crustaceans and cephalopods, two distinct samples will be taken; edible tissue and whole organism.
Omnivorous reptile	Green Turtle	Biomagnification may occur within this trophic level, and as such, will be considered in the ERA.	Due to difficult sampling requirements and limited literature regarding the relationships between reptile blood and tissue concentrations of PFAS, sampling for reptiles will not be conducted. Rather, concentrations will be calculated using semi-quantitative food-web modelling.
Carnivorous reptile	Flatback Turtle Yellow-bellied seasnake	Biomagnification may occur within this trophic level, and as such, will be considered in the ERA.	Due to difficult sampling requirements and limited literature regarding the relationships between reptile blood and tissue concentrations of PFAS, sampling for reptiles will not be conducted. Rather, concentrations will be calculated using semi-quantitative food-web modelling.
Avian omnivores	Double-banded plover	Biomagnification may occur within this trophic level, and as such, will be considered in the ERA.	Direct sampling is not proposed for avian consumers, however PFAS exposure will be addressed using semi-quantitative food-web modelling.
Avian carnivores	Pied Oystercatcher Fairy Penguin Great Cormorant	Biomagnification may occur within this trophic level, and as such, will be considered in the ERA.	Direct sampling is not proposed for avian consumers, however PFAS exposure will be addressed using semi-quantitative food-web modelling.
Herbivorous fish	Sawtail Herring Cale	Biomagnification may occur within this trophic level, and as such, will be considered in the ERA.	Nine locations (seven high priority locations) are proposed for sampling of ecologically relevant marine fish. Per the SAQP (GHD, 2017), it is proposed that five samples of each of three fish species will be collected from each location. Pending organism size, two distinct samples are proposed for each fish; edible fillet and whole organism.
Omnivorous fish	Black Bream	Biomagnification may occur within this trophic level, and as such, will be considered in the ERA.	Nine locations (seven high priority locations) are proposed for sampling of ecologically relevant marine fish. Per the SAQP (GHD, 2017), it is proposed that five samples of each of three fish species will be collected from each location. Pending organism size, two distinct samples are proposed for each fish; edible fillet and whole organism.
Carnivorous fish	Snapper Fiddler Ray Hammerhead Shark	Biomagnification may occur within this trophic level, and as such, will be considered in the ERA.	Nine locations (seven high priority locations) are proposed for sampling of ecologically relevant marine fish. Per the SAQP (GHD, 2017), it is proposed that five samples of each of three fish species will be collected from each location. Pending organism size, two distinct samples are proposed for each fish; edible fillet and whole organism.
Mammalian omnivore	Dugong	Biomagnification may occur within this trophic level, and as such, will be considered in the ERA.	Direct sampling is not proposed for marine mammals, however PFAS exposure will be addressed using semi-quantitative food-web modelling.
Mammalian carnivore	New Zealand fur seal Humpback Whale Bottlenose Dolphin	Biomagnification may occur within this trophic level, and as such, will be considered in the ERA.	Direct sampling is not proposed for marine mammals, however PFAS exposure will be addressed using semi-quantitative food-web modelling.

5.4 Exposure assessment

Contamination sources and pathways have been identified in the SAQP report (GHD 2017a) and are summarised in Section 2. The exposure assessment will use the pathways identified in the CSM and the exposure duration will be estimated. The contaminant concentrations found in the soil, sediments, water, and/or lower order biota will be used to determine potential intake of the contaminant. This exposure assessment will be validated from the current sampling program to measure the actual uptake into the biota from soil, sediment, water, and/or prey items.

- The approach is to sample biota that are readily abundant and represent key elements of the food web.
- This sampling program focuses on biota that are present in the natural environment (not domesticated animals) that have constant exposure to contaminants in the water, sediment, and/or soil.
- In addition to terrestrial, freshwater, and marine biota, soil, water and sediment samples will be collected at the proposed locations as listed in Table 4 and presented in Appendix D (the number and locations of samples to be discussed with DPAW) so that a correlation can be made between the environmental concentrations of PFAS and concentrations within the biota using a calculated bioaccumulation factor (BAF). As the bioaccumulation factors will be calculated from actual data, any uncertainties usually inherited by using international or other BAFs obtained from published literature will be removed, allowing for a high level of confidence in the risk assessment outcomes. Additionally, a qualitative assessment of biological parameters of each organism will be made upon collection and will be taken into account in the analysis of the data.

Terrestrial

- As shown in the CSM, terrestrial biota are exposed from direct contact and uptake from impacted soil, groundwater, surface water and sediments, and/or affected food items.
- A range of terrestrial flora, including grasses, roots, fruits, and flowers will be considered to determine potential uptake from soil and/or groundwater.
- Macroinvertebrates (including worms, gastropods, and insects) will be sampled to characterize exposure from direct contact with soil.
- Road kill opportunities or naturally deceased vertebrates such as kangaroo, bandicoot, swamp wallaby, etc. occurring at HMAS Creswell are expected to be the primary sources of vertebrate samples, provided time between mortality and sampling proves feasible. Additional alternatives for sampling vertebrates include Defence sponsored or National Park endorsed fox or rabbit shooting, or collection of culturally significant terrestrial biota in collaboration with WBACC.
- Deceased vertebrates will be transferred to a registered veterinarian for tissue sampling (muscle and liver).

Freshwater

- As shown in the CSM, freshwater aquatic biota are exposed from direct contact and uptake from impacted groundwater, surface water and sediments, and/or affected food items.
- Roots from macrophytes will be collected as the ecologically relevant food item to characterize exposure from groundwater, surface water and sediments.

- Invertebrates including insects, freshwater gastropods and crustaceans such as yabbies (*Cherax destructor*) have been selected as representative organisms to characterise prolonged continuous exposure in freshwater systems. Yabbies, in particular, have been identified as being the species at greatest risk of exposure from uptake from surface water and groundwater entering the creek systems. Yabbies are at greater risk from exposure to sediment than fish species due to their habit of burrowing into the sediment when water levels drop and bottom feeding which will include incidental uptake of sediments. PFAS, particularly PFOS, has the potential to accumulate in sediments with sediments occasionally higher concentrations than surface water. The maximum total PFAS concentration to date recorded during the DSI in surface water on-site was 12.0 µg/L, although this location is not expected to be of high ecological value. The maximum total PFAS concentration recorded to date during the DSI in surface water expected to have suitable yabby habitat was in Captains Lagoon at 1.93 µg/L. The maximum total PFAS concentration recorded to date during the DSI in sediment was 0.208 mg/kg. The maximum PFAS concentration to date during the DSI in sediments expected to have suitable yabby habitat was in Captains Lagoon at 0.047 mg/kg.
- Fish can also be exposed to contaminants in surface water and groundwater that infiltrates into the surface water (including by direct bioconcentration from water). Depending on the feeding habits of the fish, uptake of PFAS will occur from ingestion of aquatic invertebrates, plants and detritus. It is unlikely that the majority of native freshwater fish will have direct uptake of contaminated sediments as their diet consists of aquatic macroinvertebrates, crustaceans and molluscs, not detritus. Therefore, sampling of burrowing crustaceans in conjunction with fish sampling provides information about different receptors as they will have different exposure pathways.
- An external examination of the yabbies and fish will be conducted to determine the health and immune status of each individual. This examination will include notes on the presence of parasites (which may indicate potential compromising of the animals' immune system) and shell or fin damage. It should be noted that lower water levels may cause other forms of stress on the biota and water levels at each location will be recorded during the sampling. Control/background samples collected from Lake McKenzie will be used to assess the animals' health by comparison with the potentially impacted sites.
- Both yabbies and fish are preyed upon by birds, frogs and snakes so the above sampling program will give a clear link to higher order avian and terrestrial predators. Semi-quantitative food web modelling can be used to assess the risk to higher order reptile and avian consumers following methods developed by the US EPA (1999) using data provided in Sample et al. (1996) or other more recent publications. This type of food web modelling uses available environmental data and predicted species specific exposure parameters to estimate the intake rates of contaminants. The data collected from fish and yabby tissue samples can also be used in the human health risk assessment if required.

Marine

- As shown in the CSM, marine aquatic biota are exposed from direct contact and uptake from impacted surface water and sediments and/or affected food items. It should be noted that PFAS behave differently in saltwater than in freshwater environments. The solubility of PFOS declines in saltwater, and therefore, any contamination reaching the marine environment is expected to precipitate out into sediments and represent an on-going source of PFAS to the system.
- Macroaglae and other marine plant material will be collected to characterise exposure in marine flora.

- Invertebrates including molluscs, echinoderms, and crustaceans have been selected to characterise prolonged continuous exposure in marine systems. These organisms have prolonged exposure to both surface water and sediments and uptake through ingestion.
- Fish and cephalopods can also be exposed to contaminants in marine surface water, including by direct bioconcentration from water. However, exposure to marine fishes is expected to be dominated by dietary exposure due to the reduced solubility of PFAS in saltwater. Depending on the feeding habits of the fish and squid, uptake of PFAS will occur due to ingestion of aquatic invertebrates, macrophytes and other fish species. Depending on the fish species sampled, it is possible that the fish can have direct uptake through the marine sediments as some species target sediment dwelling organism such as amphipods.

It should be noted that this preliminary appraisal of ecological impacts is targeting the organisms at most risk of exposure and bioaccumulation of PFAS. The scientific community's current understanding is that the aquatic organisms closely associated with sediment will be most at risk of exposure to PFAS and susceptibility to bioaccumulation over terrestrial organisms. The results of this study will provide information to determine the direction of additional studies and to assess risks to higher order predator species (terrestrial, freshwater, or marine) using food web modelling.

5.4.1 Data Analysis

Exposure Point Concentrations (EPCs) are defined by NEPM (2013) as "an estimate of the concentration of the source contaminant in the medium that the population is exposed to, at the location where exposure is predicted to occur". The proposed sample plan is robust and statistically sound data is expected in most cases. Therefore, a 95% Upper Confidence Limit (95% UCL) value will be adopted as the EPC as a conservative estimate of exposure. However, in instances where the data is not considered appropriate for statistical analysis, GHD will adopt a similar method to that shown below.

Table 7 Proposed Statistical Data Analysis

Judgement	EPC Application	Justification
<9 samples and <9 detects OR ≥9 samples and ≥9 detects and <50% detects (expressed as proportion of detects)	Maximum reported concentration	The maximum reported concentration for the media/assessment areas will be adopted where there was insufficient data to conduct statistical analysis. TBC
≥9 samples and ≥9 detects and ≥50% detects (expressed as proportion of detects)	95% UCL	The 95% UCL is considered to be an appropriately conservative representation of data (as per recommendations in the ASC NEPM), provided there are sufficient data points. Professional judgement will be applied and nine or more data points have been considered to be a sufficient number for the purposes of this assessment. It is noted that the ProUCL User's Guide (US EPA, 2013) indicates that a sample size ≤6 is considered

Judgement	EPC Application	Justification
		not to produce a reliable statistical evaluation for risk assessment and remediation purposes.
Non-detect	Laboratory limit of reporting	Where PFOS or PFOA was not detected in a sampled environmental media, the laboratory limit of reporting will be adopted as an exposure point concentration in the food web modelling. However, GHD is aware that this may over-estimate the derived risk.

5.5 Toxicity assessment

Toxicity data used to derive protective concentrations to be applied to aquatic ecosystems are generally calculated from laboratory bioassays. Evaluation of bioassay data needs to also take into account the ecological setting and other factors that can affect the health of species such as drought condition, water quality and nutrient loading. Further, there is a limited amount of data available for chronic long-term exposure to PFAS. The differences between environmental and laboratory exposures were discussed by Qi *et al* (2011) who calculated a Predicted No Effect Concentration (PNEC) for PFOS of 6.66 µg/L based on species sensitivity distribution for 95 percent species protection. A 35-day NOEC was reported as 3.0 mg/L for a mesocosm (12,000 L) with freshwater zooplankton communities (Boudreau *et al* 2003), a 450-fold increase on the Qi *et al* (2011) PNEC and an 83-fold increase when compared to the RIVM (2010) maximum acceptable concentration (MAC) for freshwater ecosystems of 36 µg/L. However, on the basis of environmental ameliorating factors, the lower concentrations calculated from laboratory bioassays will provide a conservative protection level for aquatic organisms.

Limited research has been identified that determines how environmental factors modify the toxicity of PFOS and PFOA, even though the mesocosm results showed a significant decrease in toxicity to zooplankton communities when compared to laboratory studies. The mesocosm studies showed that PFOS concentrations did decrease over 8.8 percent over 35 days and did not decrease further after 285 days. However, even though concentrations in the mesocosm did not decrease significantly over the duration of the study and zooplankton populations reduced immediately following application of PFOS at 10 mg/L and 30 mg/L, resilience was observed in all species at 10 mg/L with subsequent increases in population growth observed. Sensitive species, cladocerans and copepods, showed no signs of resilience in the 30 mg/L treatment.

Similar results were obtained for an earthworm to PFOS exposure in soil over 42 days where reduced growth at lower concentrations was observed up to a 28-day exposure, however, after 42 days, reduced growth was only observed in the worms exposed to the highest concentration (Xu *et al* 2013). These results may indicate that, even though concentrations of PFOS remain in the soil, the PFOS may be less bioavailable to exposed organisms due to binding with the soil components.

The results discussed above show that the application of criteria developed using standard methods may not provide an accurate indication of effects in the receiving populations as environmental factors may influence the bioavailability of the PFAS.

The toxicity assessment stage of the risk assessment incorporates the determination of concentrations of the contaminants that have potential to cause adverse impacts to exposed species and subsequent ecological impacts and the concentrations where no adverse effects are expected. Usually, concentrations that will cause adverse harm to exposed organisms and populations have been determined, published and readily available and accepted by the

community and regulators. However, this is not the case for PFAS. The uncertainty surrounding the published Australian freshwater species protection criteria creates difficulties in determining if the detected concentrations will, in actual fact, cause adverse impacts on the exposed populations. PFAS criteria currently accepted in Australia which will be adopted during the ERA are shown in Table 8. Further, as discussed above the influence of environmental factors on the bioavailability of PFAS is not readily understood.

It should be noted that in the absence of ecological based assessment criteria in Amendment 1 or Amendment 2 of the DCD #8 document, the ecological based values presented in the superseded DCD #8 Version 1.0 (May 2015) will be adopted. GHD considers that these values are of relevance to the HHERA.

Furthermore, in the absence of ecological based assessment levels for sediment in the DCD #8 Version 1.0, GHD recommends that the PNEC for application to marine sediments in Norway of 0.22 mg/kg be adopted in the present assessment for both marine and freshwater sediments. This value will prove to be conservative for freshwater systems, due to marine sediments having lower amounts of organic carbon than freshwater or terrestrial systems. This value was used to determine terrestrial screening levels at Defence sites per DCD #8 Version 1.0 (2015).

Table 8 Interim ecological PFAS screening criteria

Source	Receptor	PFOS	PFOA	6:2 FTS
Defence Directive 8 (Ecology Guideline)	Sediment	0.22[a] mg/kg	3.73 mg/kg	-
	Freshwater	6.66 µg/L	2900 µg/L	6.5 µg/L
	Groundwater	6.66 µg/L	2900 µg/L	6.5 µg/L
OEH Draft Guidelines (2017; from DoEE Draft Guidelines (2016) and Environment Canada guidelines (2017))	Freshwater 99%	0.00023 µg/L	19 µg/L	-
	Freshwater 95%	0.13 µg/L	220 µg/L	-
	Freshwater 90%	2.0 µg/L	632 µg/L	-
	Wildlife – Mammalian diet[b]	4.6 µg/kg biota ww food	-	-
	Wildlife – Avian diet[b]	8.2 µg/kg biota ww food	-	-
	Soil – indirect – Residential and parkland	0.01 mg/kg	-	-
	Soil – direct toxicity – National parks/areas with high ecological value	6.6 mg/kg	0.65 mg/kg	-
	Soil – direct toxicity – Urban residential and public open space	32 mg/kg	17 mg/kg	-
CRC Care Interim Ecological Screening Levels (2017b)	Marine 99%	0.29 µg/L	3 mg/L	
	Marine 95%	7.8 µg/L	8.5 mg/L	
	Marine 90%	32 µg/L	14 mg/L	

[a] *The PNEC of 0.22 mg/kg for marine sediments in Norway (from Bakke et al., 2010 as reported in DCD #8 (2015))*
[b] *Data not based on species relevant to Australia*

The toxicity assessment will discuss these criteria in relation to the uptake of PFAS by biota and the outcome will provide a level of confidence in the application of the criteria to off-site habitats.

5.5.1 Toxicity reference values

Piscivorous / predatory birds and mammals can be exposed to PFAS through their diets as their prey organisms have the potential to bioaccumulate PFAS through the water, sediment and diet. Environmentally relevant dietary dose-response studies for birds and mammals to derive toxicity reference values (TRVs) are preferred over less relevant studies such as: egg injection, dermal painting or in vitro studies. TRVs are expressed as mg/kg body weight / day, and are derived

from a range of dietary doses administered to the test species to derive a chronic exposure (long-term, sub-lethal end-point). The chronic studies should include sensitive life stages: embryos, juvenile or reproductive stages and measure chronic end-points that may affect reproduction, growth and development.

Few reliable dose response studies are available to derive TRVs for bird and mammal species. No observed adverse effect level (NOAEL) and lowest observed adverse effect level (LOAEL) from avian and mammalian studies have been selected for this assessment (Newsted et al. 2005). These selected TRVs are shown in Table 9. Uncertainty factors will be applied to the avian study results as the diet of the study species will likely differ from that of the birds and mammals considered in this assessment.

GHD notes that TRVs have not been derived for PFAS species other than PFOS and PFOA, nor have TRVs been established for other classes of biota such as amphibians and reptiles.

Table 9 Summary of adopted avian and mammalian toxicity reference values

Analytes	TRV (mg/kg BW/day)		Toxicity Endpoint	Reference
	NOAEL	LOAEL		
Avian				
PFOS	0.077	0.77	Reproductive endpoints (e.g., reduction in fertility, hatchability and offspring survival)	The adopted TRVs are based on data obtained from reproductive studies on the Bobwhite Quail (Newsted et al., 2005). Uncertainty factor of 10 was used to convert chronic LOAEL to a chronic NOAEL.
PFOA	0.077	0.77	PFOS used as surrogate in absence of chemical-specific TRVs	
Mammalian				
PFOS	0.1	0.4	Reproductive endpoints (e.g., decreased litter size, birth weight and pup survival, and developmental abnormalities) based on singular and multi-generational rat and rabbit studies	The TRV has been adopted based on results of four studies on rats and rabbits (Environment Canada, 2006; Stahl et al., 2011; RIVM, 2010; Dietz et al., 2015). No uncertainty factors applied.
PFOA	6.2	7.6	Reproductive endpoints in rats and mice (e.g., decreased pup body weight, behavioural effects [reduced motor coordination], vascular mineralization in testes, tubular hyperplasia in ovaries)	The TRV is the calculated geometric mean of LOAEL and NOAEL values from eight mammalian studies on mice and rats (ASTDR, 2015). No uncertainty factors applied.

5.6 Risk characterisation

As discussed above, the acute and chronic toxic effects of PFAS in exposed organisms can be difficult to determine, particularly at concentrations detected in the receiving environment and influences of environmental factors on bioaccumulation. Therefore, the bioaccumulation potential of PFAS through the food web becomes the main driver of ecological impact as calculated from actual data. As such, the species considered most at risk from continuous exposure outlined above, have been targeted for sampling to provide data that can be used to determine comprehensive bioaccumulation factors, thus eliminating uncertainty factors inherent in PFAS risk assessments. The results from the soil, water, sediment and biota analysis will comprise the main line of evidence in a weight of evidence approach to assess the ecological risk to the receiving environment of PFAS originating from JBRF and HMAS Creswell. The approach discussed above will provide a "worst case scenario" that the next stage in this investigation can be based on, to determine potential bioaccumulation in higher order predators.

The outcome of the risk characterisation will provide information to assess the potential for contaminants derived from JBRF and HMAS Creswell to enter terrestrial, freshwater, or marine organisms and thus bioaccumulate through the food web to higher order consumers (possibly including humans). The outcome will have a high reliability due to the use of site derived data and minimal use of data from international models.

6. Summary

GHD is currently conducting an Environmental Investigation associated with the historical use of AFFF containing PFAS at JBRF and HMAS Creswell in New South Wales.

The analytical results received to date indicate that PFAS is present within on-site soils and surface waters of Flat Rock Creek and Captains Lagoon at concentrations in excess of the adopted human health and ecological based assessment criteria, which are derived from various published guidelines relevant to New South Wales.

With reference to the DER (2014) guidelines, a HHERA assessment should be carried out when a Tier 1 screening assessment (i.e. the comparison of analytical results with published non site-specific assessment levels) does not, or cannot, adequately assess the level of risks posed by contamination at the site. Therefore, GHD recommends that, upon completion of the DSI (i.e. once all soil, sediment, groundwater, surface water and biota analytical data has been received), a HHERA be completed.

This HHERA Plan and Methodology has been prepared to outline to Defence and the various stakeholders the proposed approach and methodology for the HHERA based on our current body of knowledge. The HHERA will be conducted in accordance with the methodologies presented in the NEPC (2013) guidelines and other relevant guidance described within this HHERA Plan and Methodology. It is important to note that upon completion of the DSI, including evaluation of all data and refinement of the CSM, the methodology for the HHERA will be reviewed and revised as necessary. This will include further consideration to specific receptor locations, exposure pathways and exposure concentrations.

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8. Limitations

This report has been prepared by GHD for Department of Defence and may only be used and relied on by Department of Defence for the purpose agreed between GHD and the Department of Defence as set out in Section 1 of this report.

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

The services undertaken by GHD in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope limitations set out in the report and in our proposal dated 20 December 2016.

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

The opinions, conclusions and any recommendations in this report are based on assumptions made by GHD as described in this report. GHD disclaims liability arising from any of the assumptions being incorrect.

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The opinions, conclusions and any recommendations in this report are based on information obtained from, and testing undertaken at or in connection with, specific sample points. Site conditions at other parts of the site may be different from the site conditions found at the specific sample points.

Investigations undertaken in respect of this report are constrained by the particular site conditions, such as the location of buildings, services and vegetation. As a result, not all relevant site features and conditions may have been identified in this report.

Site conditions (including the presence of hazardous substances and/or site contamination) may change after the date of this Report. GHD does not accept responsibility arising from, or in connection with, any change to the site conditions. GHD is also not responsible for updating this report if the site conditions change.

Appendix A – Concentrations of soil, sediment, groundwater and surface water samples from on-site sampling

LEGEND

- HMAS Creswell / JBRF Boundary
- Water Bodies
- Drainage Areas
- Major Waterways
- Contours
- Concrete sample
- Soil sample
- Sediment sample

0 50100 200 300 400 500 600 700 800
Metres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

DRAFT

Department of Defence
HMAS Creswell and Jervis Bay Range Facility

Concentration plan for PFHxS and PFOS (sum) - Soil and Sediment

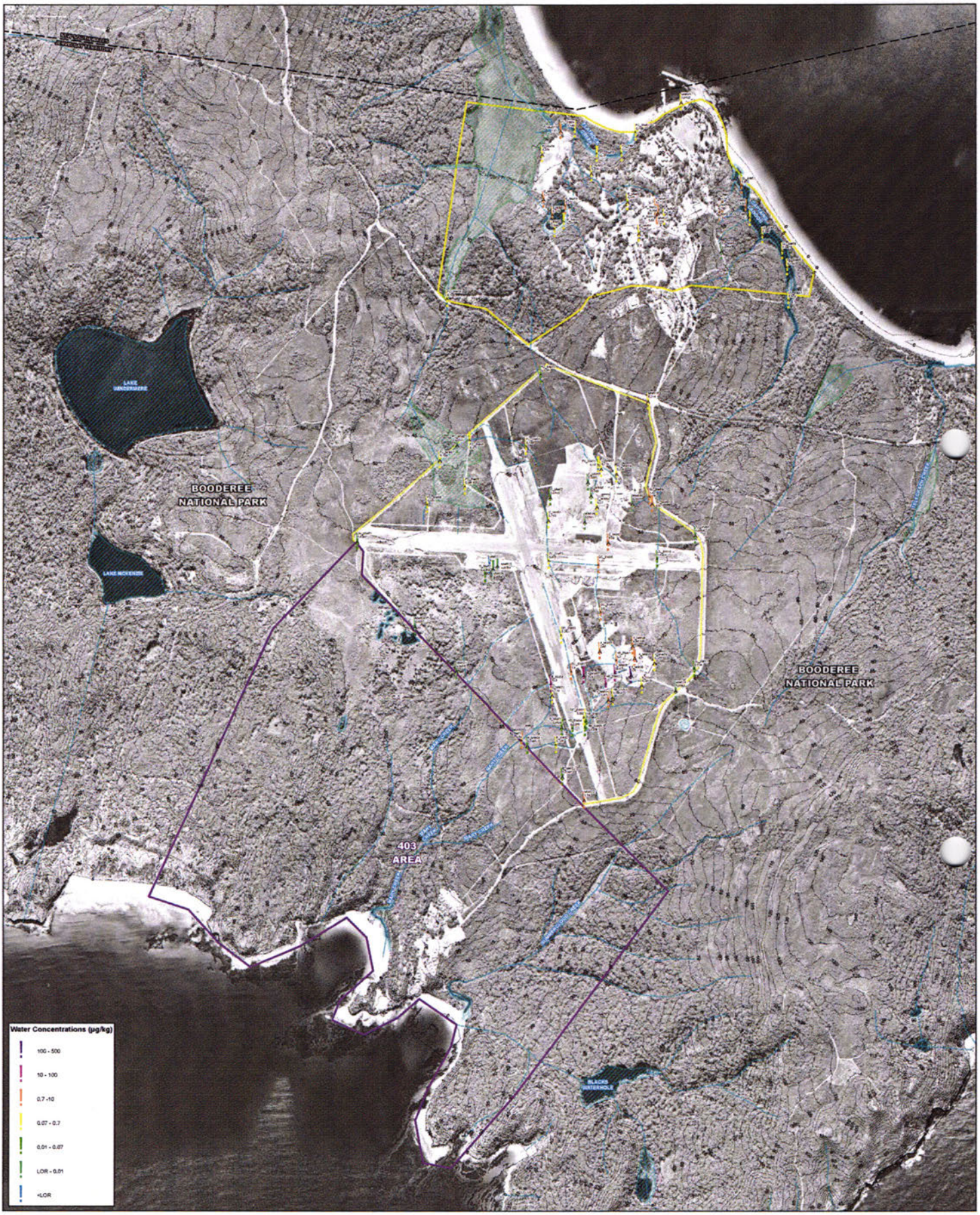
Job Number 21-26171
Revision A
Date 07 Aug 2017

Figure A

G:\21\26171\GIS\Maps\Deliverables\21_26171_D010_Concentrations_PFHxS_Soil_PORTRAIT.mxd

Data source: Imagery - Land and Property Information (2017); Streets, Waterways, Contours - NSW LPI 2015 DTDB; Contours - NSW LPI 2016; Created by: mweber

180 Lonsdale Street Melbourne VIC 3000 Australia T 61 3 8687 8000 F 61 3 8687 8111 E melmail@ghd.com W www.ghd.com



LEGEND

HMAS Creswell / JBRF Boundary
Water Bodies
Drainage Areas
Major Waterways
Contours
Groundwater sample
Surface Water sample

0 50100 200 300 400 500 600 700 800
Metres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

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HMAS Creswell and Jervis Bay Range Facility

Concentration plan for PFHxS and PFOS (sum) - Surface Water and Groundwater

Job Number 21-26171
Revision A
Date 07 Aug 2017

Figure B

G:\21\26171\GIS\Maps\Deliverables\21_26171_Z011_ConcentrationsPFHxS_Water_PORTRAIT.mxd

Data source: Imagery - Land and Property Information (2017); Streets, Waterways, Contours - NSW LPI 2015 DTDB; Contours - NSW LPI 2016, Created by:mweber

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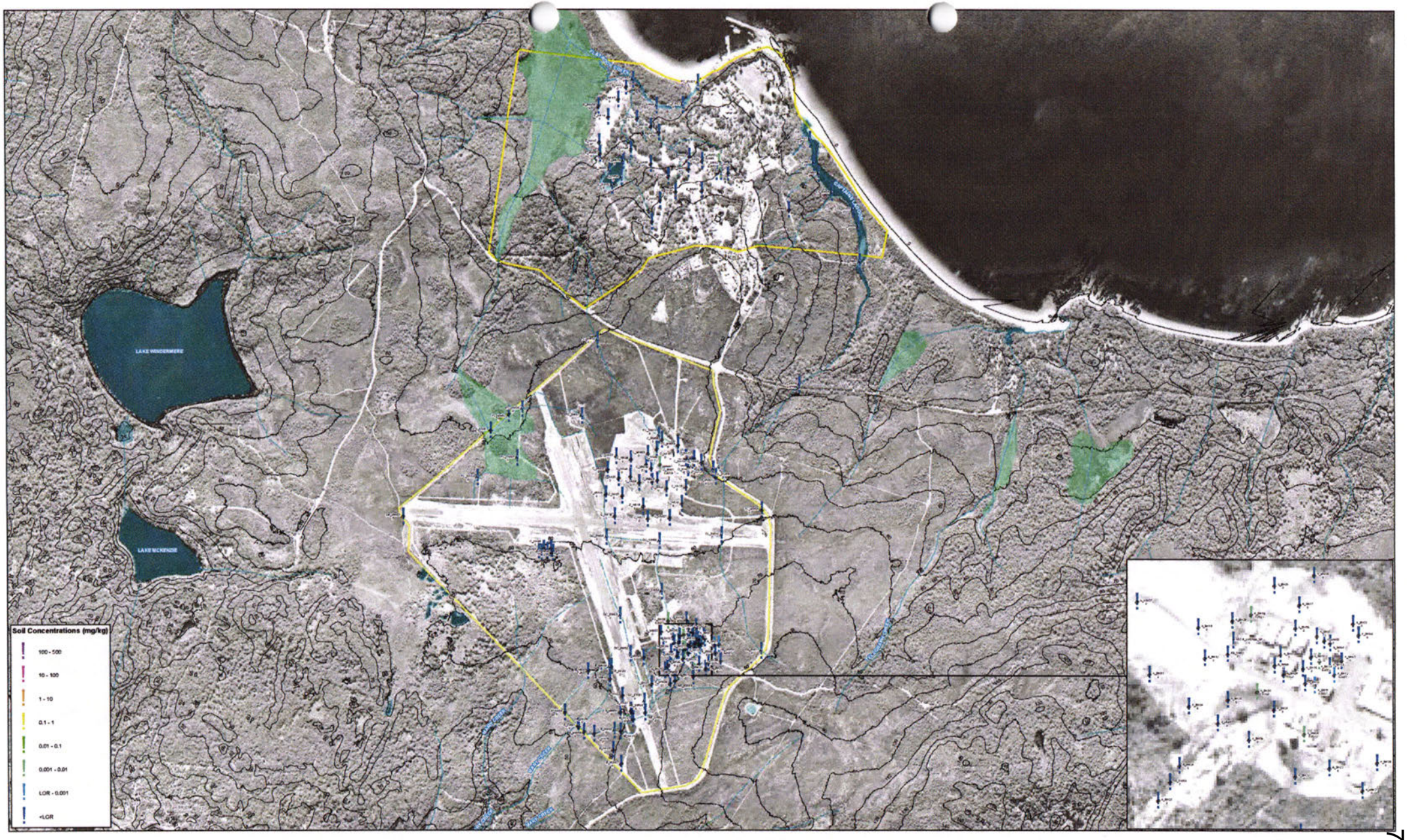

Paper Size A1

0 0.1 0.2 0.4 0.6 0.8 1

Kilometres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

LEGEND

- HMAS Creswell / JBRF Boundary
- Major Waterways
- Water Bodies
- Drainage Areas
- Contours
- Concrete sample
- Soil sample
- Sediment sample

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Department of Defence
HMAS Creswell and Jervis Bay Range Facility

Job Number 21-26171
Revision A
Date 18 Jul 2017

Concentration plan for 6:2 Fluorotelomer Sulfonate (6:2 FTS) - Soil and Sediment

Figure C

Hazelwood Drive (cnr Lignite Court) Morwell VIC 3840 Australia T 61 3 5136 5800 F 61 3 5136 5888 E mwlmail@ghd.com W www.ghd.com