

Detailed Site Investigation

RAAF Base Richmond - PFAS Investigation

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Table of Contents

Executive Summary		i
1.0	Introduction	1
1.1	Preamble	1
1.2	The Site and AFFF Use	1
1.3	Objectives of the Detailed Site Investigation	1
1.4	Context of the Detailed Site Investigation	1
1.5	Scope of Works	2
1.5.1	Early Works Program	2
1.5.2	Detailed Site Investigation	3
1.6	Data Quality Objectives	5
1.6.1	Step 1 – State the Problem (define the problem that necessitates the study)	6
1.6.2	Step 2 – Identify the Goal of the Study	6
1.6.3	Step 3 – Identify Information Inputs	6
1.6.4	Step 4 – Define the Boundaries of the Study	7
1.6.5	Step 5 – Develop the Analytical Approach	7
1.6.6	Step 6 – Specify Performance or Acceptance Criteria	8
1.6.7	Step 7 – Optimise the Design for Obtaining Data	9
1.7	Assessment of Data Quality	9
2.0	Site Identification and Background	11
2.1	The Site	11
2.2	Study Area	11
2.3	Environmental Setting	12
2.3.1	Topography	12
2.3.2	Climate	12
2.3.3	Geology	13
2.3.4	Hydrogeology	15
2.3.5	Surface Water	15
2.3.6	Sensitive Local Environmental Receptors	20
2.4	Historical AFFF Review	20
2.4.1	AFFF Formulations	20
2.4.2	Fire Training Grounds and Other Training Areas	21
2.4.3	Emergency Response	21
2.4.4	AFFF Testing	21
2.4.5	AFFF Storage	22
2.4.6	Fire Tenders	22
2.4.7	Other Information	22
2.5	Water Use Survey	23
2.6	Potential On-Site Sources of PFAS	23
2.6.1	Primary Sources	23
2.6.2	Secondary Sources	24
2.7	Potential Off-Site Sources of PFAS	24
2.8	Site and Contaminant Characteristics and Limitations of Environmental Investigation	25
2.9	PFAS Characteristics	30
2.9.1	Key PFAS Migration Processes	30
2.9.2	Physical and Chemical Properties of PFOS, PFOA and PFHxS	30
2.9.3	PFAS Analysis and Data Interpretation Issues	32
2.10	Previous Investigations	32
2.10.1	Noel Arnold and Associates, 2011	32
2.10.2	GHD, 2016	34
2.10.3	Jacobs, 2016	34
2.10.4	Other Environmental Investigations	34
2.11	Data Characteristics and Uncertainties	34
3.0	Approach and Methodology	39

3.1	Sampling Rationale	39
	3.1.1 SAQP	39
	3.1.2 Sampling Rationale	39
3.2	Methodology	42
	3.2.1 Soil	42
	3.2.2 Groundwater	43
	3.2.3 Surface Water	44
	3.2.4 Sediment Sampling	45
	3.2.5 Sample Quality Control	45
3.3	Laboratory Analysis	46
3.4	Quality Assurance and Quality Control	46
3.5	Assessment Criteria	46
	3.5.1 Overview	46
	3.5.2 PFAS Assessment Criteria	47
4.0	Results	50
4.1	Water Use Survey	50
4.2	Rainfall	51
4.3	Subsurface Conditions	52
4.4	Hydrogeology	54
	4.4.1 Groundwater Bore Search	54
	4.4.2 Groundwater Elevation	54
	4.4.3 Groundwater Flow Direction	54
	4.4.4 Groundwater Geochemical Parameters	55
	4.4.5 Hydraulic Conductivity based on Particle Size Distribution	55
	4.4.6 Hydraulic Conductivity based on Slug Testing	56
4.5	Surface Water	57
	4.5.1 Surface Water Conditions	57
	4.5.2 Surface Water Geochemical Parameters	64
4.6	Sediment Observations	64
4.7	Soil Analytical Results: Unsaturated Zone	65
	4.7.1 PFAS in Unsaturated Zone	65
	4.7.2 Non-Contaminant Analyses	66
4.8	Soil Analytical Results: Saturated Zone	66
4.9	Groundwater Analytical Results	66
	4.9.1 PFAS	67
	4.9.2 Non-Contaminant Analyses	67
4.10	Surface Water Analytical Results	68
	4.10.1 PFAS	68
	4.10.2 Non-Contaminant Analyses	69
4.11	Sediment Analytical Results	69
	4.11.1 PFAS	69
	4.11.2 Non-Contaminant Analyses	70
4.12	AFFF Concentrate	70
5.0	Discussion	72
5.1	Subsurface Geological Conditions	72
	5.1.1 Lowlands Formation	72
	5.1.2 Clarendon Formation	72
	5.1.3 Londonderry Clay	73
	5.1.4 Rickabys Creek Gravel	73
	5.1.5 Wianamatta Group	73
5.2	PFAS in Soil	73
	5.2.1 On-Site	73
	5.2.2 Off-Site	73
5.3	Hydrogeology	74
	5.3.1 Thickness and Extent of Aquifers	74
	5.3.2 Groundwater Recharge	74
	5.3.3 Groundwater Elevation Contours	75
	5.3.4 Horizontal Hydraulic Gradients	75

	5.3.5	Groundwater Composition as Evidence of Flow Direction	76
	5.3.6	Hydraulic Conductivity Estimates	76
	5.3.7	Groundwater Flow Velocity Estimates	77
5.4		PFAS Groundwater Impacts and Fate and Transport	77
	5.4.1	Groundwater Impacts - On-Site	77
	5.4.2	Groundwater Impacts - Off-Site	78
	5.4.3	Implications of Sub-surface Conditions on the Extent of PFAS in Groundwater	79
5.5		PFAS Nature and Extent in Surface Water and Sediment	80
	5.5.1	Surface Water Topography and Drainage	80
	5.5.2	PFAS Migration to Surface Water	80
	5.5.3	Nature and Extent of Surface Water and Sediment PFAS Impacts	80
	5.5.4	Spatial Variability in Surface Water Concentrations	84
	5.5.5	Flooding and PFAS Movement	85
	5.5.6	Windblown Transport of PFAS	86
5.6		Data Gaps	86
6.0		Conceptual Site Model	87
6.1		Introduction	87
	6.1.1	Purpose	87
	6.1.2	Essential Elements of a CSM	87
6.2		Summary of Sources of Contamination	87
	6.2.1	Primary Sources	87
	6.2.2	Secondary Sources	88
6.3		Migration Mechanisms	88
6.4		Exposure Pathways	89
6.5		Potential Receptors	89
	6.5.1	On-Site Receptors	90
	6.5.2	Off-Site Receptors	90
	6.5.3	Potential Ecological Receptors	90
6.6		Summary	90
7.0		Conclusions	98
8.0		References	99
9.0		Limitations	102
Appendix A			
		Figures	A
Appendix B			
		Tables	B
Appendix C			
		Previous Environmental Investigations	C
Appendix D			
		Graphs	D
Appendix E			
		Borelogs	E
Appendix F			
		Survey Data	F
Appendix G			
		Supporting Documents	G
Appendix H			
		Plates	H
Appendix I			
		Laboratory Certificates	I

Appendix J		
	Data Validation	J
Appendix K		
	Water Use Survey	K
Appendix L		
	Post Rainfall Sampling Event	L
Appendix M		
	Non-PFAS Analytes	M

List of Tables

Table 1	Compounds analysed in the extended PFAS suite	4
Table 2	The seven steps in defining DQOs	5
Table 3	Acceptance Criteria for Data Quality Indicators for Sample Analysis	10
Table 4	Site Description	11
Table 5	SA features	12
Table 6	Summary of monthly rainfall records at the Site (1994 – 2017)	13
Table 7	Key Geological Units in the SA	14
Table 8	Summary of Clarendon and Lowland Formation aquifers properties based on previous works	15
Table 9	On-site surface water catchment areas	17
Table 10	Potential Off-Site Sources of PFAS	24
Table 11	Environmental Aspects and Characteristics	26
Table 12	Physical and chemical properties of PFOS, PFOA and PFHxS	31
Table 13	Identified forms of variability in the data and strategies to reduce variability	36
Table 14	Sampling Rationale	40
Table 15	Soil Investigation Methodologies	42
Table 16	Groundwater Investigation Methodologies	43
Table 17	Surface Water Investigation Methodologies	44
Table 18	Sediment Investigation Methodologies	45
Table 19	Sample Quality Control	45
Table 20	PFAS criteria summary: human health	47
Table 21	PFAS criteria summary: Ecological	49
Table 22	Summary of responses to the Water Use Survey based on 157 surveys returned to date	50
Table 23	Rainfall conditions during fieldwork	52
Table 24	Summary of subsurface conditions	52
Table 25	Summary of groundwater elevations	54
Table 26	Summary of surface water geochemical parameters	55
Table 27	Hydraulic Conductivity Estimates from Particle Size Distributions	55
Table 28	Summary of hydraulic conductivity based on slug tests	56
Table 29	Summary of surface water observations	58
Table 30	Summary of surface water geochemical parameters	64
Table 31	Summary of sediment observations	64
Table 32	Summary of PFAS in unsaturated soil on-Site	65
Table 33	Summary of PFAS in unsaturated soil off-Site	66
Table 34	Summary of non-contaminant analyses in unsaturated soil	66
Table 35	Summary of PFAS in saturated soils	66
Table 36	Summary of PFAS in groundwater on-Site	67
Table 37	Summary of PFAS in groundwater off-Site	67
Table 38	Summary of PFAS in groundwater in residential bores	67
Table 39	Summary of non-contaminant analytes in groundwater	67
Table 40	Summary of PFAS in surface water, on-Site	68
Table 41	Summary of PFAS in surface water, off-Site	69
Table 42	Summary of non-contaminant analytes in surface water	69

Table 43	Summary of PFAS in sediment, on-Site	70
Table 44	Summary of PFAS in sediment, off-Site	70
Table 45	Summary of non-contaminant analytes in sediment	70
Table 46	Summary of PFOS, PFOA and PFOS + PFHxS in AFFF concentrate	71
Table 47	Comparison of PFOS + PFHxS with depth	74
Table 48	Comparison between creek depth and groundwater depth at selected locations in the LFA	75
Table 49	Horizontal Hydraulic Gradients	76
Table 50	Mid Screen Cation Exchange Capacity, Total Organic Carbon and Iron	79
Table 51	Conceptual Site Model – On-Site	91
Table 52	Conceptual Site Model – Off-Site	94

Glossary

Glossary	
ADF	Australian Defence Force
AFFF	Aqueous Film Forming Foam
ALS	Australian Laboratory Services Pty Ltd
AHD	Australian Height Datum
AMG	Australian Map Grid
AQIS	Australian Quarantine and Inspection Services
ASC NEPM	Assessment of Site Contamination National Environment Protection Measure 1999 (as amended 2013)
BoM	Bureau of Meteorology
CEC	Cation Exchange Capacity
CFA	Clarendon Formation Aquifer
CoC	Chain of Custody
CoPCs	Contaminants of Potential Concern
CSM	Conceptual Site Model
CSR	Contaminated Sites Register
Defence	Department of Defence
DSI	Detailed Site Investigation
DQIs	Data Quality Indicators
DQOs	Data Quality Objectives
EC	Electrical Conductivity
ECC	Environmental Clearance Certificate
EMP	Environmental Management Plan
ERA	Ecological Risk Assessment
EWP	Early Works Program
GDE	Groundwater Dependant Ecosystem
HASP	Health and Safety Plan
HHRA	Human Health Risk Assessment
IBC	Intermediate Bulk Container
LDPE	Low Density Polyethylene
LFA	Lowlands Formation Aquifer
LOR	Limit of Reporting
m AHD	Meters Above Horizontal Datum
m bgs	Meters below ground surface
m btoc	Meters below top of casing
MEOMS	Mechanical Equipment Operations and Maintenance Section
NATA	National Association of Testing Authorities

Glossary	
NDD	Non-Destructive Drilling
NEPC	National Environment Protection Council
NSW	New South Wales
OCP	Organochlorine Pesticides
OPP	Organophosphorus Pesticides
PAH	Polycyclic Aromatic Hydrocarbons
PFAS	per- and poly-fluoroalkyl substances A list of PFAS considered in this investigation is provided in Table 1 .
PFOA	Perfluorooctanoic Acid
PFOS	Perfluorooctane Sulfonate
PMAP	Property Management Action Plan
POP	Persistent Organic Pollutant
QA/QC	Quality Assurance / Quality Control
RAAF	Royal Australian Air Force
RPD	Relative Percent Difference
SA	Study Area
SAQP	Sampling and Analysis Quality Plan
SOP	Standard Operating Procedure
STP	Sewage Treatment Plant
SWL	Standing Water Level
The Base	RAAF Base Richmond
The Site	The Base and Rickabys Drop Zone
TOC	Total Organic Carbon
TRH	Total Recoverable Hydrocarbons
TWP	Trade Waste Plant
USCS	Unified Soil Classification System
VOC	Volatile Organic Compounds
SVOC	Semi Volatile Organic Compounds

Executive Summary

Background

AECOM Australia Pty Ltd (AECOM) was engaged by the Department of Defence (Defence) to undertake an Early Works Program and a Detailed Site Investigation (DSI), both of which are reported herein, at the Royal Australian Air Force (RAAF) Base Richmond (the Site) located at Dight Street, Richmond, NSW. The DSI also included the investigation of the surrounding off-Site areas. The Site and the Study Area (SA) are presented on **Figure 1** and **Figure 2** in **Appendix A** respectively.

The first stage of the Project¹ involved desktop studies and the Early Works Program (which included preliminary sampling of groundwater, sediment and surface water) to develop a Preliminary Conceptual Site Model (CSM). The preliminary CSM described potential per- and poly-fluoroalkyl substances (PFAS) sources, PFAS migration pathways and potential human and environmental receptors. The preliminary CSM was then used to inform the development of a Sampling, Analysis and Quality Plan (SAQP) for the DSI. The DSI involved the sampling of groundwater, surface water, soil and sediment both on the Site and within the (SA). The DSI also included the collection of soil characterisation, water quality and hydrogeological data to describe conditions within the SA.

The fieldwork for the DSI was completed between October 2017 and February 2018, with a supplementary groundwater gauging event completed in May 2018. This report presents the outcomes of the Project works completed to date, including the updated CSM. The outcomes of this report will be used to inform the Human Health Risk Assessment (HHRA), Environmental Risk Assessment (ERA) and PFAS Management Area Plan (PMAP), which are currently being developed.

The Site has been an active airbase since 1925 and is currently an important air logistics hub for the Australian Defence Force. As part of typical airbase activities, aqueous film forming foam (AFFF) was used at the Site for fire training and emergency response from around 1976. 3M Lightwater™ was the main AFFF product in use at the Site until approximately 2004, and is known to have contained PFAS, including perfluorooctane sulfonate (PFOS) and perfluorooctanoic acid (PFOA).

Objectives

The objectives of the DSI were to derive environmental data that will enable:

- Evaluation of the nature of PFAS at source zones on the Site;
- Assess the nature and extent of PFAS impact, and whether background sources not related to the Site may exist and could contribute towards the presence of PFAS off-Site;
- Refine the CSM developed during the EWP.
- Generate data to assist in scoping and planning PFAS management options.

Sources of PFAS Contamination

The DSI identified five key PFAS source zones on the Site – (1) the Former Fire Training Ground; (2) Hangar 54; (3) Former Fuel Farm 1; (4) Fuel Farm 2; and (5) the Sewage Treatment Plant (STP).

Secondary PFAS source zones are likely to have developed where PFAS impacted water has migrated or been concentrated and can leach to groundwater. Locations include: overflows and leakage at the STP and the Trade Waste Plant (TWP), as well as the underground and open drainage networks both on and off-Site.

¹ The Project includes the Early Works Program, Detailed Site Investigation, Human Health Risk Assessment, Environmental Risk Assessment and PFAS Management Area Plan.

Extent of PFAS Contamination

The on-Site PFAS source zones have contributed to a PFAS plume in groundwater of approximately 2 km in length and 5 km in width (refer to **Figure 28** in **Appendix A**).

All major on-Site drainage systems were found to contain concentrations of PFAS greater than the laboratory limit of reporting and/or the adopted assessment criteria, with detections also found at locations where surface water discharges from the Site. These locations include discharge into Rickabys Creek and its tributaries, and Bakers Lagoon.

Ultimately, all surface water discharges into major drainage networks and creeks flowing from the Site towards the Hawkesbury River.

Conceptual Site Model

The CSM has been refined based on the analytical results from multiple media within the SA, the results of the water use surveys and information received from NSW Department of Primary Industry (DPI). Within the SA, surface water bodies are used extensively for irrigation and this pathway has been included in the CSM.

The refined CSM and data generated in the DSI will be used to inform the HHRA and ERA for the Site. The DSI, HHRA and ERA will ultimately inform the scoping and planning of future management options for the Site, which will be detailed in the PMAP.

Potential risks to Human Health and the Environment

Concentrations of PFAS in the samples collected were compared to assessment criteria adopted from guideline values presented in the PFAS National Environmental Management Plan (NEMP). Where concentrations exceed these criteria, further assessment is required to understand whether there is an unacceptable risk to human health and / or the environment.

Next Steps

The HHRA (currently under development) will assess multiple pathways to evaluate the potential human health risks from PFAS exposure to identified receptors within the SA. The HHRA will consider direct contact PFAS exposures through environmental media (e.g. soil, groundwater, surface water, and sediment) as well as secondary exposures via dietary intakes, including both seafood and home-grown plant and animal produce (garden crops, eggs and pasture). This assessment includes a review of toxicological profiles in accordance with the National Environmental Protection Measure (NEPM) process and the PFAS NEMP, and will utilise data from the DSI.

The ERA is currently being developed to assess the potential risks from the identified PFAS compounds to ecological receptors with habitats present within the SA, and the potential for wider ecosystem impacts to result from the accumulation of PFAS in terrestrial and aquatic organisms exposed to PFAS contamination.

Finally, a PMAP will be developed, which will outline actions to manage risks confirmed in the HHRA and ERA. The PMAP will include an Ongoing Monitoring Plan to monitor migration of PFAS in the future.

1.0 Introduction

1.1 Preamble

AECOM Australia Pty Ltd (AECOM) has prepared this Detailed Site Investigation (DSI) Report as part of the *Lead Consultant For Comprehensive Investigation of PFAS Site Conditions* package of works at RAAF Base Richmond and Rickabys Drop Zone (the Site) and the surrounding area. The Site location is presented in **Figure 1** in **Appendix A** and the Site boundary and surrounding land (collectively referred to as the “Study Area” [SA]) are presented on **Figure 2** in **Appendix A**.

An independent NSW EPA Accredited (land contamination) Site Auditor, Mr Mark Stuckey of Environmental Earth Sciences Pty Ltd (‘the Auditor’), is engaged by Defence to review the DSI undertaken by AECOM.

1.2 The Site and AFFF Use

RAAF Base Richmond was the first Air Force Base to be established in New South Wales (NSW), and the second within Australia. In 1925 the first Air Force element in NSW, No.3 Squadron, was formed at Richmond. From 1923 to 1936 the Site was also used as a supplementary aerodrome for Sydney. During World War II, Richmond developed into a base of major importance in Australia’s defence, and has since evolved to become the home of Air Mobility Group and Number 84 Wing. The base is a strategically important air logistics hub for the Australian Defence Force. As part of typical airbase activities, aqueous film forming foam (AFFF) was used at the Site for fire training and emergency response from approximately 1976.

AFFF formulations historically used at the Site contained a range of per- and poly-fluoroalkyl substances (PFAS), including perfluorooctane sulfonate (PFOS) and perfluorooctanoic acid (PFOA). Between approximately 1976 and 2003/2004, the main AFFF product in use at the Site was 3M Lightwater™ which contained PFAS, including PFOS and PFOA.

1.3 Objectives of the Detailed Site Investigation

The objectives of the DSI is to build a data set that will enable:

- Further evaluation of the nature of PFAS at source areas on the Site
- Assessment of the nature and possible extent of PFAS arising from the Site, and whether background sources (not related to the Site) may exist and could be contributing towards the PFAS impacts identified
- Refining of the Conceptual Site Model (CSM) describing source-pathway-receptor linkages by:
 - Improving the understanding into the historical use of AFFF at the Site and in surrounding areas; and
 - Generating data with regard to the extent of PFAS concentrations greater than the analytical Limit of Reporting (LOR), on and off-Site to assist in identifying the potentially exposed human and ecological receptors, and evaluate pathways by which they may be exposed.
- Increase the data set to assist in scoping and planning PFAS management options (if required).

1.4 Context of the Detailed Site Investigation

Tasks undertaken by AECOM from April 2017 to March 2018 for the DSI have included:

- **Early Works Program (this Report):** sampling of on-Site groundwater and surface water and sediment from both on- and off-Site to focus the inform the intrusive investigations of the DSI.
- **Detailed Site Investigation (this Report):** the investigation has included; investigation of on- and off-Site PFAS concentrations in soil, sediment, surface water, groundwater; hydrogeological investigations; review of previous investigations; review of the historical use of AFFF at the Site; and the development of a CSM.

- **Off-Site Human Health Risk Assessment (HHRA – in preparation):** development of a multiple pathway HHRA to evaluate the potential human health risks from PFAS exposure to identified receptors within the SA. The HHRA will include consideration of direct contact PFAS exposures through environmental media (e.g. soil, groundwater, surface water, and sediment) as well as secondary exposures via dietary intakes, including both seafood and home-grown plant and animal produce (garden crops, eggs and pasture). This assessment includes a review of toxicological profiles in accordance with the National Environmental Protection Measure (NEPM) process and the PFAS National Environmental Management Plan (NEMP), and will utilise data from the DSI.
- **Ecological Risk Assessment (ERA – in preparation):** assessment of the potential risks from the identified PFAS compounds to ecological receptors with habitats present within the SA, and the potential for wider ecosystem impacts to result from the accumulation of PFAS in terrestrial and aquatic organisms exposed to PFAS contamination. This assessment includes an ecological survey, and will utilise data from the DSI.
- **Stakeholder and Community Engagement:** facilitation of stakeholder and community engagement activities related to the DSI and associated tasks including land access, water use surveys and community information events.
- **Property Management Action Plan (PMAP):** at the completion of the DSI, HHRA and ERA, a PMAP will be prepared. The PMAP will communicate Defence's roadmap of activities to be undertaken to address risks to human health and the environment. The PMAP will communicate Defence's objectives, strategic activities, priorities and anticipated timeframes.

1.5 Scope of Works

1.5.1 Early Works Program

The scope of work performed during the Early Works Program (EWP) included the following:

Surface water, sediment and groundwater sampling:

- Establishment of a compound at the Site
- Gauging and sampling of 65 existing groundwater monitoring wells located on Base
- Collection of 19 primary co-located surface water and sediment samples, including:
 - 11 samples from locations within Rickabys Drop Zone
 - 3 samples from locations on Base
 - 5 samples from locations off-Site.
- Collection of field measured surface water and groundwater geochemical parameters
- Recording of GPS coordinates in MGA94 at the sampling locations.

PFAS laboratory analysis:

- Laboratory analysis of selected, groundwater, surface water and sediment samples for the full suite of PFAS compounds, as listed in **Table 1**, below
- Analysis of all primary and intra-laboratory samples by Australian Laboratory Services Pty Ltd (ALS), a NATA accredited laboratory for the Standard Minimum PFAS suite in accordance with Technical Memorandum 1652034-060-M-Rev2
- Analysis of inter-laboratory samples by Envirolab Services Pty Ltd (Envirolab), a NATA accredited laboratory for the Standard Minimum PFAS suite in accordance with Technical Memorandum 1652034-060-M-Rev2.

Total Organic Carbon (TOC) and Cation Exchange Capacity (CEC):

- Analysis of 5 primary sediment samples for TOC and CEC. This data was collected to assist in characterising PFAS sorption.

Water chemistry:

- Analysis of 65 primary groundwater and 5 primary surface water samples for major ions to assess water chemistry, to better understand interactions between groundwater and surface water and interactions between aquifers.
- Selected groundwater and surface water samples were analysed for dissolved metals (including aluminium, manganese and iron).

1.5.2 Detailed Site Investigation

The scope of work performed in the DSI was in accordance with the DSI Sampling and Analysis Quality Plan (SAQP) (AECOM, 2017a) with the following exceptions:

- Monitoring well MW86 was relocated from adjacent the intersection of Cornwallis Road and Cuppits Lane was moved south of Rickabys Drop Zone adjacent Pericival Street. Relocation of MW86 provided additional delineation of the groundwater plume to the east of the Base.
- Additional co-located surface water and sediment locations (SW032/SD032, SW033/SD033, SW034/SD034, SW035/SD035, SW036/SD036 and SW037) were also included in the DSI.
- A data gap gauging event was conducted in May 2018 to refine potentiometric contours with a larger data set to that proposed in the DSI SAQP (AECOM, 2017a).

The variations to the scope of work listed above, in general have increased the data set to that proposed in the DSI SAQP (AECOM, 2017a).

Soil and groundwater sampling and hydrogeological testing:

- Underground service clearance at all sampling locations.
- Borehole drilling and soil profile logging.
- Installation of 25 new groundwater monitoring wells using sonic and hollow stem auger drilling techniques.
- Surveying the elevation of the top of the monitoring well casings to meters Australian Height Datum (m AHD) and coordinates as easting and northing in Map Grid Australia 1994 (MGA94)
- Laboratory analysis of 49 soil samples.
- Collection of groundwater samples from monitoring wells, following stabilisation of field measured geochemical parameters (including temperature, pH, electrical conductivity [EC] and redox) from 24 groundwater monitoring wells, with one groundwater monitoring well (MW94) being dry and not sampled.
- Completion of 'slug' tests at 8 groundwater wells, to provide field estimates of the hydraulic conductivity of the aquifer(s).

Surface water and sediment sampling and hydrogeological investigation:

- Collection of 17 primary sediment samples and 18 primary surface water samples.
- Collection of field measured surface water geochemical parameters.
- Recording of GPS coordinates in MGA94 at the sampling locations.

PFAS laboratory analysis:

- Laboratory analysis of selected soil, groundwater, surface water, sediment samples for the full suite of PFAS compounds, as listed in **Table 1**, below.

Table 1 Compounds analysed in the extended PFAS suite

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

Screening analysis for non-PFAS Contaminants of Potential Concern (CoPC):

- Selected soil, groundwater, surface water and sediment samples from the Site were analysed for non-PFAS CoPC, as listed above in the EWP laboratory analysis suite.

Total Organic Carbon (TOC) Cation Exchange Capacity (CEC) and Particle Size Distribution (PSD):

- Analysis of 10 primary soil samples and 21 primary sediment samples for TOC and COC, and 7 soil samples for PSD. These data were collected to assist in the confirmation of field soil texture

observations used to estimate hydraulic conductivity and to assist interpretation of PFAS migration.

PFAS sorption coefficients:

- Analysis of 4 primary soil samples for PFAS concentrations. These samples were collected from the saturated zone at approximately the mid-point of the screened interval of the monitoring well installed at various drilling locations. These soil data were compared with groundwater PFAS results from the same well to develop Site specific sorption coefficients to assist the understanding of PFAS retardation during transport with lateral groundwater flow.

Water chemistry:

- Analysis of 24 primary groundwater samples for major ions and dissolved metals (aluminium, manganese and iron) to assess water chemistry and to better understand interactions between aquifers if multiple aquifers are present.

1.6 Data Quality Objectives

The amended National Environmental Protection Measure (NEPM, Schedule B [2]) Guideline on-Site Characterisation (2013) specifies that the nature and quality of the data produced in an investigation will be determined by the Data Quality Objectives (DQOs). As referenced by the NEPM, the DQO process is detailed in the United States Environmental Protection Agency (US EPA) *Guidance on Systematic Planning Using the Data Quality Objectives Process (EPA QA/G-4 : EPA/240/B-06/001), February 2006*.

The US EPA defines the process as ‘a strategic planning approach based on the Scientific Method that is used to prepare for a data collection activity. It provides a systematic procedure for defining the criteria that a data collection design should satisfy, including when to collect samples, where to collect samples, the tolerable level of decision errors for the study, and how many samples to collect’.

The process of establishing appropriate DQOs is defined according to the following seven steps:

Table 2 The seven steps in defining DQOs

Step	Data Quality Objective Step
1	State the problem – Define the problem that necessitates the study; identify the planning team, examine budget, schedule.
2	Identify the goal of the study – State how environmental data will be used in meeting objectives and solving the problem, identify study questions, define alternative outcomes.
3	Identify information inputs – Identify data and information needed to answer study questions.
4	Define the boundaries of the study – Specify the target population and characteristics of interest, define spatial and temporal limits, scale of inference.
5	Develop the analytic approach – Define the parameter of interest, specify the type of inference, and develop the logic for drawing conclusions from findings.
6	Specify performance or acceptance criteria – Develop performance criteria for new data being collected or acceptable criteria for existing data being considered for use.
7	Develop the plan for obtaining data – Select the resource-effective sampling and analysis plan that meets the performance criteria.

The approach adopted relative to the seven steps presented above is detailed in the DSI SAQP (AECOM, 2017a).

1.6.1 Step 1 – State the Problem (define the problem that necessitates the study)

- Widespread PFAS presence was detected on-Site and at the Base boundaries in all media during the EWP. The off-Site extent of PFAS presence in multiple media (groundwater, surface water, sediment, soil and biota) is unknown
- The potential for migration of PFAS is not fully understood
- The exposure and uptake of PFAS in the environment by biological receptors is unknown
- The exposure link between PFAS in the environment and human receptors is unknown.

The groundwater, surface water, sediment, and soil data collected during the DSI has provided a more detailed understanding of the extent of PFAS presence in multiple media, and has enabled refinement of the CSM.

While the presence of PFAS in biota is currently not understood, assessment of this media is not presented in the DSI SAQP. The outcomes of the works undertaken as part of the DSI SAQP will be used to further inform the SAQP being developed as part of the human health and ecological risk assessment scopes.

1.6.2 Step 2 – Identify the Goal of the Study

The decision / goal represents the key steps/issues that have been reviewed/considered in order to resolve the problem identified in Step 1.

The primary question to be addressed is the following:

- Are the CoPC detectable in the groundwater, surface water, and/or sediment in association with historic use of AFFF at the Site and surrounding areas?

The data collected to answer this question have been used in developing and refining the CSM, informing future on and off-Site investigation works, and will be utilised in the human health and/or ecological risk assessments.

Defence will use the information to establish what management strategies are required, if any, to address potential risks associated with CoPC presence.

The key issues are:

1. Do existing data identify CoPC presence?
2. Is the data valid and sufficient to undertake a human health and ecological risk assessment, if required?
3. Are the laboratory Limits of Reporting (LOR) appropriate for the objectives of the investigation?
4. Are concentrations of CoPC present within the boundaries of the investigation above laboratory LOR for the CoPC?
5. Has the extent of the CoPCs (as evidenced from presence in multiple sample media) been identified?
6. Is the investigation approach scientifically suitable and defensible?

1.6.3 Step 3 – Identify Information Inputs

To allow assessment of the data against the study goal listed in Step 2, the following will be considered:

- Previous results from sampling conducted by other parties, during the EWP, and other data collected at the Site and surrounding areas
- New data collected and observations made during field works to be conducted as outlined in **Section 1.5**
- Results of the Water Use Survey
- Interviews conducted with key Defence personnel, associated with the use of AFFF on-Base, are discussed in **Section 2.4**

- Results of analysis of samples to be collected as outlined in **Section 1.5**.

1.6.4 Step 4 – Define the Boundaries of the Study

The spatial boundaries are:

- Lateral: on-Site areas defined by the Site boundary under Defence ownership. Off-Site areas include those defined on figures in **Appendix A**
- Vertical: groundwater samples have been collected from monitoring wells installed at various depths with the purpose of assessing the vertical extent of PFAS compounds. Sampling depths varied spatially;
 - Soil focused primarily on the shallow subsurface, up to 2 m below ground surface (bgs)
 - Groundwater samples were collected to a maximum depth of 24 m bgs
 - Sediment samples were collected from the surface to shallow subsurface as defined in **Table 14**.

Temporal boundaries were limited to the proposed fieldwork timeframes, between October 2017 and January 2018. At the time of writing sampling of surface water post rainfall events had not been conducted due to insufficient rainfall during the fieldwork timeframes.

The final location of boreholes was dependent on a number of factors, including; the presence of buried structures, the presence of overhead wires, the presence of adequate flat, firm ground to place a drill rig safely, proximity to traffic and incorporation of new data.

1.6.5 Step 5 – Develop the Analytical Approach

The decision rules can be defined as:

- If the laboratory quality assurance/quality control data are within the acceptable ranges, the data will be considered suitable for use
- If the CoPC are reported above the laboratory LOR in one or more samples, then it will be considered whether further assessment or management measures are required
- If the CoPC are reported below the laboratory LOR in the samples applicable to a specific pathway, then it will be considered that there is no evidence of a potential complete source-pathway-receptor linkage and, therefore, inclusion of that pathway in the risk assessment may not be required. For example, if CoPC concentrations in shallow soils on-Site were reported as below the laboratory detection limit, then the pathway to terrestrial ecological receptors from soil exposure may be considered incomplete.

The decision on the acceptance of the analytical data was made on the basis of the Data Quality Indicators (DQIs) as follows:

- **Precision:** A quantitative measure of the variability (or reproducibility) of data
- **Accuracy:** A quantitative measure of the closeness of reported data to the “true” value
- **Representativeness:** The confidence (expressed qualitatively) that data are representative of each media sampled
- **Completeness:** A measure of the amount of useable data from a data collection activity
- **Comparability:** The confidence (expressed qualitatively) that data may be considered to be equivalent for each sampling and analytical event.

1.6.5.1 Precision

Suitable criteria and/or performance indicators for assessment of precision include:

- Performance of intra-laboratory duplicate sample sets through calculation of relative percent differences (RPDs)
- Performance of inter-laboratory duplicate sample sets through calculation of RPDs

- The RPDs will be assessed as acceptable if less than or equal to 30% as per the NEPM Schedule B3. Where the results show greater than 30% difference, a review of the cause will be conducted (NEPM, 2013). It is noted that RPDs that exceed this range may be considered acceptable where:
 - Results are less than 10 times the LOR (no limit)
 - Results are less than 20 times the LOR and the RPD is less than 50%
 - Heterogeneous materials are encountered.

1.6.5.2 Accuracy (Bias)

The closeness of the reported data to the “true” value is assessed through review of performance of:

- Method blanks, which are analysed for the analytes requested for in the primary samples
- Matrix spikes and surrogate recoveries
- Laboratory control samples.

1.6.5.3 Representativeness

To ensure the data produced by the laboratory are representative of conditions encountered in the field, the following steps will be taken by the laboratory, and subsequently reviewed by AECOM:

- Blank samples will be run in parallel with field samples to confirm there are no unacceptable instances of laboratory cross-contamination
- Review of RPD values for field and laboratory duplicates to provide an indication that the samples are generally homogeneous, with no unacceptable instances of significant sample matrix heterogeneity
- The appropriateness of collection methodologies, handling, storage and preservation techniques will be assessed to ensure/confirm there was minimal opportunity for sample interference or degradation (e.g. volatile loss during transport due to incorrect preservation / transport methods).

1.6.5.4 Completeness

In validating the degree of completeness of the analytical data sets acquired during the program, the following has been considered:

- Whether standard operating procedures (SOPs) for sampling protocols have been adhered to
- Copies of all Chain of Custody (CoC) documentation are reviewed and presented.

It can therefore be considered whether the proportion of “useable data” generated in the data collection activities is sufficient for the purposes of assessing the problem as stated in Step 1 above.

1.6.5.5 Comparability

Given that assessment data has comprised several data sets from separate sampling events (for example, the EWP and DSI sampling activities), issues of comparability between data sets are reduced through adherence to SOPs and regulator endorsed or made guidelines and standards on each data gathering activity.

In addition, the data will be collected by experienced AECOM field staff, and NATA accredited laboratories will be employed in all laboratory programs for soil, sediment and water analysis.

1.6.6 Step 6 – Specify Performance or Acceptance Criteria

Specific limits for this investigation are in accordance with the appropriate guidance made or endorsed by state and national regulations, appropriate indicators of data quality, and standard procedures for field sampling and handling.

This step also examines the certainty of conclusive statements based on the available new data collected. This should include the following points to quantify tolerable limits:

- A decision can be made based on a certainty assumption of 95% confidence in any given data set. A limit on the decision error will be 5% that a conclusive statement may be a false positive or false negative.

A decision error in the context of the decision rule presented above would lead to either underestimation or overestimation of the risk level associated with a particular sampling area. Decision errors may include:

- Sampling errors may occur when the sampling program does not adequately detect the variability of a contaminant from point to point across the SA. To address this, the DSI SAQP outlines minimum numbers of samples proposed to be collected from each media. As such, there may be limitations in the data if aspects of the DSI SAQP cannot be implemented. Some examples of this scenario include, but are not limited to:
 - Proposed surface water sample locations may be dry at the time of sampling
 - Proposed samples are not collected due to access being restricted to a given location.
- Limitations in ability to acquire useful and representative information from the data collected. The data are proposed to be collected from multiple locations and sample media. For example:
 - Inability to collect surface water and sediment samples at the same location.
- Measurement errors can occur during sample collection, handling, preparation, analysis and data reduction. To address this, the following measures are proposed:
 - Field staff to follow SOPs when undertaking samples, including decontamination of tools, removal of adhered sediment to avoid false positives in results, and use of appropriate sample containers and preservation methods
 - Laboratories to follow a standard procedure when preparing samples for analysis and undertaking analysis
 - Laboratories to report quality assurance/ quality control data for comparison with the DQIs established for the project.

1.6.7 Step 7 – Optimise the Design for Obtaining Data

Optimisation of the data collection process was achieved by:

- Working closely with the analytical laboratories and sampling equipment suppliers to ensure that appropriate procedures and processes are developed and implemented prior to and during the field work, to ensure that sample handling, and transport to and processing by the analytical laboratories is appropriate.
- Conducting sampling according to set SOPs for the type of sampling being conducted (e.g. groundwater monitoring well sampling). SOPs are presented in the DSI SAQP (AECOM, 2017a).

1.7 Assessment of Data Quality

The quality of data collected as part of the sampling has been assessed on a range of factors including:

- Documentation and data completeness
- Data quality – comparability, representativeness, precision and accuracy of the analytical data.

The target for data completeness is to achieve 95% of data as suitable for use.

The acceptance criteria for DQIs for samples are specified in **Table 3**.

Table 3 Acceptance Criteria for Data Quality Indicators for Sample Analysis

Data Quality Indicators	Acceptance Criteria
Water, Sediment and Soil Samples	
Rinsates (where sampling equipment is reused)	Less than the laboratory LOR.
Field duplicates/Inter-lab duplicates	<p>The RPDs will be assessed as acceptable if less than or equal to 30% as per the NEPM Schedule B3. Where the results shows greater than 30% difference, a review of the cause will be conducted (NEPM, 2013). It is noted that RPDs that exceed this range may be considered acceptable where:</p> <ul style="list-style-type: none"> • Results are less than 10 times the LOR (no limit); • Results are less than 20 times the LOR and the RPD is less than 50%; and • Heterogeneous materials are encountered.
Laboratory duplicates	<p>RPDs less than:</p> <ul style="list-style-type: none"> • 20% for high level laboratory duplicates (i.e. >20 x LOR); and • 50% for medium level laboratory duplicates (i.e. 10 to 20 x LOR).
Matrix spikes	Recoveries between 70-130% of the theoretical recovery or as nominated in the laboratory's QC report, based on their historical database.
Method blanks	Less than the laboratory LOR.
Laboratory control samples	Recoveries between laboratories specified range for each particular analyte / analytical suite.

2.0 Site Identification and Background

2.1 The Site

The Site, an active airbase, comprises approximately 414 hectares of land approximately 55 km to the north west of the Sydney CBD and is located in the Hawkesbury City Council local government area, as shown in **Figure 1** in **Appendix A**. In summary:

- The Site is an active RAAF Base and a critical Defence facility
- The Site has become the home of Air Mobility Group and Number 84 Wing. The base is a strategically important air logistics hub for the Australian Defence Force. The Site is zoned 'SP1 Aerodrome/Defence Services' under the Hawkesbury Local Environment Plan, 2012. The Site comprises 'landside' and 'airside' areas.
 - Landside areas are partly covered by hardstand and pavement consisting of concrete, asphalt roadways and low rise buildings which include accommodation properties and facilities.
 - Airside areas consist of taxiways, aprons and the main runway.

The Site comprises three distinct areas outlined in **Table 4** below.

Table 4 Site Description

Area		Location Description
The Site	The Base	Surrounded by Richmond Road to the south, Percival Street to the east, Dight Street to the north and residential and commercial properties to the west.
	The Sewage Treatment Plant (STP) and Trade Waste Plant (TWP)	Located to the north of the main Base on the northern side of Dight Street. The STP and TWP are bound to the east, north and west by intensive plant agriculture (primarily turf farming).
	Rickabys Creek Drop Zone (floodplain area)	This area is Defence owned land and considered part of the Site, bound by Percival Street to the west, Ingolds Lane and land used for intensive plant agriculture to the north, Rickabys Creek in the east and private property to the south. This area contains Fuel Farm 2, the third Base hospital and numerous smaller support service buildings.

2.2 Study Area

The SA is shown in **Figure 2**.

Table 5 Study Area features

Aspect	Details
Site	The area of the Site is approximately 414 ha, and is located 55km to the north west of Sydney. The site details are provided in Section 2.1 .
Study Area	<p>The SA boundary was developed by AECOM on consideration of surface water drainage patterns and groundwater flow directions in the region and preliminary results of the EWP surface water and groundwater PFAS concentrations.</p> <p>The SA is shown in Figure 2 in Appendix A. This area is approximately 16 km² and encompasses parts of the suburbs of Richmond, Windsor and Cornwallis.</p> <p>The SA comprises:</p> <ul style="list-style-type: none"> • Semi-rural land uses, predominantly consisting of intensive plant agriculture (turf farming) and scattered market gardens located within Cornwallis (north and east of the Site). • Land with primarily single dwelling houses to the west of the site within the suburb of Richmond. Immediately west of the Site is a small light industrial area and St Monicas Primary School. • Bakers Lagoon, which occupies approximately 10.8 ha located north of the site (shown in Figure 2 in Appendix A). • Major surface water drainage, including: <ul style="list-style-type: none"> - Northern tributaries of Rickabys Creek, Cooleys Creek and Bakers Lagoon, located to the north of the Site. - Rickabys Creek located to the south of the Site. - Hawkesbury River located to the east of the Site. <p>The land zoning within the SA includes:</p> <ul style="list-style-type: none"> • E2 Environmental Conservation (Bakers Lagoon) • IN2 Light Industrial • R2 Low Density Residential • R3 Medium Density Residential • RE1 Public Recreation • RE2 Private Recreation • RU2 Rural Landscape • SP1 Special Activities

2.3 Environmental Setting

2.3.1 Topography

The SA is characterised by a series of wide, flat alluvial terraces occurring at varying elevations above the Hawkesbury River. The majority of the Site lies on an elevated terrace defined by the Clarendon Formation and ranges from 18 to 22 m AHD (refer to **Figure 3** in **Appendix A**). This terrace includes much of the Richmond urban area and localities such as the Richmond golf course. Further to the north and east of the Site, an abrupt drop to a flood plain of the Hawkesbury River exists and is associated with the Lowland Formation. This lower flood plain terrace lies at approximately 6-12 m AHD and includes the STP, Rickabys Drop Zone, and the surface drainage system of natural and modified drains related to Rickabys Creek and Cooleys Creek.

2.3.2 Climate

The Bureau of Meteorology (BoM) Richmond RAAF weather station (number 067105) has recorded data since 1993 and presents a record of approximately 24 years. Review of the BoM data indicates the following:

- Average minimum monthly temperatures vary from 3.6°C in July to 17.8°C in February and February with the lowest recorded temperature of -5.2°C on 12 July 2002
- Average maximum monthly temperatures vary from 17.6°C in July to 30.2°C in January. The highest recorded temperature was 47.0°C on 11 February 2017
- Mean rainfall at the Site is 741.2 mm per annum. The lowest recorded annual rainfall was 490.6 mm in 2006 and the highest annual rainfall was 1,051.2 mm in 2007. The highest monthly rainfall generally occurs between November and March (averaging ≥ 77 mm per month), with the lowest rainfall in April to October (averaging 45 mm per month).

A summary of the lowest, average and highest monthly rainfall recorded at the Site is presented in **Table 6**. A graphical representation of daily and monthly rainfall during the sampling period is presented in **Appendix D**.

Table 6 Summary of monthly rainfall records at the Site (1994 – 2017)

Month	Average Monthly Rainfall (mm)	Lowest Monthly Rainfall mm (year)	Highest Monthly Rainfall mm (year)
January	84.4	18.2 (2009)	266.4 (2016)
February	115.5	8 (2000)	255.6 (2008)
March	80.1	12.8 (2016)	286.8 (2017)
April	59	2.2 (1997)	353 (2015)
May	46.1	2.8 (2008)	168.4 (1998)
June	57.2	1.2 (2001)	246.8 (2007)
July	28.4	0.6 (2017)	105.8 (1999)
August	33.9	0 (1995)	159 (1998)
September	46.1	0.2 (2017)	158 (1995)
October	47.4	1 (2002)	233.4 (2004)
November	79.5	13.8 (2009)	159.8 (2005)
December	69.7	14.6 (1997)	229.4 (2014)

Data source – Bureau of Meteorology (BoM) RAAF Richmond station (station number 067105)

2.3.3 Geology

The Site is located within the Cumberland Basin, a low lying, gently dipping Tertiary aged basin situated at the western margin of the Sydney Basin (Jones and Clark, 1991). The main geological units of the Cumberland Basin in the Hawkesbury-Nepean area are outlined in **Figure 4** and are based on the Penrith 1:100,000 Geological Map (NSW Geological Survey). The base of the Cumberland Basin is characterised by Upper Triassic shales and sandstones of the Wianamatta Group, and represents the last deposition before younger, more unconsolidated, alluvial and fluvial deposition during the Tertiary to Holocene periods.

The Tertiary to Holocene units are detailed in **Table 7** below. Initial fluvial and alluvial deposition in the Cumberland Basin comprised the Rickabys Creek Gravel and the Londonderry Clay. Towards the late Tertiary and early Pleistocene, basin subsidence and erosion of these initial fluvial and alluvial deposits formed alluvial terraces (i.e. the Londonderry Road and Blacktown Road areas near Londonderry) (Jones and Clark 1991). Falling sea levels during the Pleistocene glacial period resulted in further fluvial deposition (Clarendon Formation and Lowlands Formations).

Table 7 Key Geological Units in the Study Area

Geological Period	Geological Epoch	Age (Ma)	Unit	General Description	Approx. Thickness (m)
Quaternary	Holocene	< 0.01	Undifferentiated sediments and alluvium (Qal and Qa)	Gravel banks, sand islands and points bars related to the Hawkesbury-Nepean River and tributary streams (i.e. Rickabys Creek).	Up to 10m
	Pleistocene to mid - Holocene	1.8 – 0.01	Lowlands Formation (Qpl)	Comprised of an upper unit of orange-grey clay, silt and fine sand which is underlain by a gravel and coarse sand sub-unit. The formation forms a broad terrace adjacent to the Hawkesbury River to the north of the Site. The base of the formation lies unconformably on top of the Wianamatta Group.	5 – 17m
	Pleistocene to early - Holocene	2.6 – 0.01	Clarendon Formation (Qpd)	Red-fawn coloured fine grained clayey sand and clayey silt with increasing clay towards the base of the formation. Occasional sand and gravel at the base of the unit. Forms a terrace below the Tertiary terrace (Londonderry Clay and Rickabys Creek Gravel) and approximately 10m above the lower terrace of the Lowlands Formation. The Site is located largely on the Clarendon Formation terrace.	4 - 8m
Neogene	Miocene	23 - 5	Londonderry Clay (Tl)	Mottled red-grey impervious clay with ferruginous ironstone pisolites and sand lenses. Lateritic nodules very common.	1 - 9m
	Miocene	23 - 5	Rickabys Creek Gravel (Tr)	Poorly sorted gravel with a high matrix content of silt and sand. Fines upwards into a gradational boundary with the overlying Londonderry Clay. Likely to be continuous across the entire Cumberland Basin.	2 - 12m
Triassic		240-230	Wianamatta Group (Rwb, Rwm, Rwa)	Basal unit of the Cumberland Basin comprised predominantly of shale and minor sandstone.	<150m

2.3.4 Hydrogeology

Regional aquifers identified include fractured rock aquifers and younger tertiary unconsolidated aquifers.

2.3.4.1 Fractured Rock Aquifers

Fractured rock aquifers include the Wianamatta Group and the Hawkesbury Sandstone which both have variable groundwater yields (Jones and Clark 1991). The Hawkesbury Sandstone aquifer has historically been the most reliable water source in the region with uses for irrigation, stock water and domestic purposes. The Wianamatta Group aquifer is characterised by yields of 0.2 - 5.5 L/s and higher salinity making it typically unsuitable for stock watering. Typical salinity for the Hawkesbury Aquifer ranges 200 – 1200 mg/L.

2.3.4.2 Unconsolidated Aquifers

Younger, unconsolidated aquifers that provide more accessible water supply to areas surrounding the Site include the Clarendon Formation Aquifer (CFA) and Lowlands Formation Aquifers (LFA). General characteristics of the CFA and LFA are provided below in **Table 8** and are based on a review of 18 existing bores from the NSW Office of Water (OoW) and the previous investigation of Noel Arnold and Associates (2011) The majority of bores publically listed on the (NSW OoW) targeted the LFA.

Table 8 Summary of Clarendon and Lowland Formation aquifers properties based on previous works

Clarendon Formation Aquifer (CFA)	
Main water bearing lithology	Silty sand, coarse sand and coarse gravels at depths ranging from 10.6 – 21 mbgs (Noel Arnold and Associates, 2011).
Groundwater elevation (m AHD)	4.0 – 7.5 mAHD
Groundwater flow direction	NE inferred flow towards the NW tributaries of Rickabys Creek, Bakers Lagoon and Hawkesbury River.
Horizontal hydraulic conductivity	0.02 – 2.4 m/day, based on slug testing of selected wells by Noel Arnold and Associates (2011).
Salinity (mg/L)	Fresh to brackish: 73 – 3960 mg/L (Noel Arnold and Associates, 2011; NSW OoW 2018).
Lowland Formation Aquifer (CFA)	
Main water bearing lithology	Silty fine sands and minor gravelly sands. Water strike typically at 2 – 3 mbgs
Groundwater elevation (m AHD)	4.3 – 6 mAHD
GW flow direction	NE inferred flow towards the Rickabys Creek Tributary, Bakers Lagoon and Hawkesbury River (Noel Arnold and Associates, 2011).
Horizontal hydraulic conductivity	0.01 – 0.37 m/day, based on slug testing of selected wells by Noel Arnold and Associates, 2011.
Salinity (mg/L)	Fresh to brackish: 13 - 2838 mg/L (Noel Arnold and Associates, 2011)

2.3.5 Surface Water

2.3.5.1 Surface Water Setting

The Site is surrounded by a network of interconnected rural drains, lagoons, creeks and rivers (**Figure 5** in **Appendix A**), including:

- Pughs Lagoon, located approximately 3 km west of the Site
- Bakers Lagoon, located approximately 1 km to the north
- Rickabys Creek, located to the south and east
- Cooleys Creek, located to the north

- Hawkesbury River, located to the west, north and east.

The SA lies within the Hawkesbury Nepean River catchment.

2.3.5.2 On-Site Surface Water

Drainage Network

There are no natural watercourses or natural water bodies at the Site; however several formed surface water drainage networks, constructed wetland systems and settlement ponds are present.

Based on a series of site inspections and a review of aerial imagery and maps, there appears to be no drains flowing directly onto the Site, with the exception of stormwater runoff from Percival Street which acts as the division of Base operations and Rickabys Drop Zone. This indicates that limited surface water inflow from surrounding surface water networks migrates on-Site.

Swale Drain Upgrades

Between January and March 2016, the airside surface water swale drain system on-Site was upgraded to address surface water ponding in localised topographic depressions and to prevent future road deterioration associated with stormwater erosion (Department of Defence, 2015).

The newly constructed swale drains, sub-soil drains and culverts were designed to address the objectives described above, as well as enable the Site to meet Australian Quarantine and Inspection Service (AQIS) biosecurity standards which requires the Site to have no standing water after two rain-free days (SKM, 2011).

Surface Water Catchments

The surface water drainage network comprises a combination of engineered open swale drains, underground stormwater pipes, pits, culverts and detention storage. A series of water and stormwater quality management plans have been undertaken to define the surface water catchments on-Site (ERM, 2005; ERM, 2008).

A summary of the catchments, including the presence of identified PFAS source zones, is provided in **Table 9** below. The catchments are shown in **Figure 5** in **Appendix A**.

Surface water and sediment samples were not obtained from these catchments during the EWP and DSI field programs. This was due to the relatively small catchment areas and the ephemeral nature of surface water flows in drains, as well as the absence of natural water courses or water bodies.

Table 9 On-site surface water catchment areas

Catchment	Area (m ²)	Description	Potential PFAS Source Zone	Discharge Point	Off-Site Receptors
A	8,647	Catchment A is located to the north east of Percival Street and includes Fuel Farm 2, as well as stormwater runoff from Percival Street.	- Fuel Farm 2	Discharges to constructed wetland system on Rickabys Drop Zone	Rickabys Creek, Hawkesbury River
B	3,485	Catchment B is located to the east of the Site and is bounded by the runway, Hawkesbury Valley Way and Percival Street. This catchment comprises mostly open grassed areas.	None identified	Discharges to a drainage channel off-Site on Percival Street	Rickabys Creek, Hawkesbury River
C	93,869	Catchment C is the largest catchment on-Site and includes most of the runway, plane refuelling areas and the majority of hangars and associated flight line infrastructure.	- Fire Station (Building 291) - Hangar 54 - Tanker Parking Area - Former Fuel Farm 1 - Areas used by fitters - Fire vehicle parking - Tarmac fuel spills and incidents	Discharges to the Settlement Pond on Rickabys Drop Zone	Rickabys Creek, Hawkesbury River
D	75,543	Catchment D is located in the north west of the Site. The majority of the catchment is grass covered however infrastructure including the Light Plane Flying Club, residential areas and Defence offices, a small section of the runway, occur in this catchment.	- Former Fire Training Ground - Airfield Foam Cannon Testing Area - Airfield incidents and spills	Discharges to an open drain to the west of the STP Settlement Ponds before discharging off-Site to a rural drain	North western tributary of Rickabys Creek, Rickabys Creek, Hawkesbury River.
E	5,916	Catchment E is located to the north of the Site and includes roadways, residential areas and Defence offices.	None identified	Discharges to a stormwater system before discharging off-Site to the north of the STP into a rural drain	North western tributary of Rickabys Creek, Rickabys Creek, Hawkesbury River.

Catchment	Area (m ²)	Description	Potential PFAS Source Zone	Discharge Point	Off-Site Receptors
F	3,375	Catchment F is located to the north of the Site and includes grassed areas and a light industrial area. The TWP, an identified PFAS source area, is located in this catchment however treated waste is transported off-Site and the facility is not connected to the stormwater system.	- TWP	Discharges to a stormwater system before discharging off-Site to the north of the STP into a rural drain	North western tributary of Rickabys Creek, Rickabys Creek, Hawkesbury River.
G	18,700	Catchment G is located to north east of the Site spanning both sides of Percival street and includes residential buildings, the hospital and grassed areas.	None identified	Discharges to a constructed wetland system on Rickabys Drop Zone	North western tributary of Rickabys Creek, Rickabys Creek, Hawkesbury River.

2.3.5.3 Off-Site Surface Water Network

The Site is surrounded by natural watercourses to the south, east and north as well as an interconnected network of rural drains on the Richmond Lowlands located to the north of the Site. Surface water from the Site discharges to rural drains to the north, as well as directly into Rickabys Creek to the east.

Northern Tributaries of Rickabys Creek

A series of unnamed rural drains to the north west, north and north east form a network of tributaries that flow through the Richmond Lowlands. Review of the topography indicates the headwaters of the drainage network commences at Pughs Lagoon approximately 3 km to the west of Site and adjacent to Richmond Township (refer to **Figure 3** in **Appendix A**). Surface water flows generally in an easterly direction through rural properties to combine at the northern boundary of the Site at Rickabys Drop Zone, before flowing along the south eastern Site boundary before intersecting Rickabys Creek approximately 2 km upstream of its junction with the Hawkesbury River.

Rickabys Creek

The headwaters of Rickabys Creek are located approximately 13 km to the south of the Site near Cranebrook. The creek traverses residential and rural land use areas flowing generally in a northern direction towards Windsor, before crossing under the Hawkesbury Valley Way and flowing along the boundary of the Site. At the eastern boundary of Rickabys Drop Zone, the creek is intersected by its northern tributaries which combine and flow generally in a north eastern direction towards the junction with the Hawkesbury River at Windsor.

Cooleys Creek

A series of ephemeral, unnamed rural drains to the west and north west of the Richmond Lowlands form a surface water network that drain into Bakers Lagoon at the headwaters of Cooleys Creek. Additionally, treated effluent from the on-Site STP is transferred through an underground pipe and discharge into Bakers Lagoon. At the southern boundary of the lagoon, Cooleys Creek flows in an easterly direction through rural properties for approximately 3 km before the junction with the Hawkesbury River.

Hawkesbury River

At the confluence of the Nepean and the Grose Rivers at Yarramundi, the Hawkesbury River is formed flowing in a north easterly direction past the township of North Richmond, before meandering to the east through Freemans Reach and on to Windsor. The river is tidally influenced with a tidal limit being described as extending to Yarramundi (Department of Environment and Climate Change NSW, 2009), refer to **Figure 2** in **Appendix A**, however the difference in tidal range is small and has been found to be approximately 0.3 m (Public Works Department of NSW, 1987).

The intake for the North Richmond Water Filtration Plant (which supplies potable water to Richmond) is upstream of Windsor and the Site and several wastewater treatment plants discharge treated effluent into the Hawkesbury Nepean river system (Sydney Water, 2017) including:

- North Richmond
- Wallacia
- Winmalee.

Additionally, the following water recycling plants may discharge excess or precautionary discharges to the Hawkesbury Nepean river system (Sydney Water, 2017);

- Picton
- West Camden
- Penrith
- Richmond.

2.3.6 Sensitive Local Environmental Receptors

Conservation Areas

Bakers Lagoon is listed zoned E2, Environmental Conservation under the Hawkesbury Local Environment Plan, 2012 (HCC, 2012), refer to **Figure 2** in **Appendix A**.

Groundwater Dependent Ecosystems (GDE)

BoM's Groundwater Dependent Ecosystems Atlas was reviewed and the following highly likely GDE were identified within the SA:

- Bakers Lagoon (aquatic GDE, terrestrial GDE), refer to **Figure 2** in **Appendix A**
- Cumberland River Flat Forest (terrestrial GDE), scattered within the SA.

Ecology within the SA

A search of the Department of the Environment and Energy's (DoEE) Protected Matters Search Tool identified a number of threatened ecological species which are known to occur or known to have habitat within the 5km of the Site this includes:

- Birds:
 - Regent Honey Eater (*Anthochaera phrygia*)
 - Australasian Bittern (*Botaurus pocoliloptilus*)
 - Curlew Sandpiper (*Calidris ferruginea*).
- Mammals:
 - Koala (*Phascolarctos cinereus*)
 - Grey-headed Flying Fox (*Pteropus poliocephalus*).
- Plants:
 - Bynoe's Wattle, Tiny Wattle (*Acacia bynoeana*)
 - Downy Wattle, Hairy Stemmed Wattle (*Acacia pubescens*)
 - Spiked Rice-flower (*Pimelea spicata*)
 - Sydney Plains Greenhood (*Pterostylis saxicola*).
- Terrestrial ecosystems
- Aquatic ecosystems (Streams and the Hawkesbury River)

2.4 Historical AFFF Review

AECOM has completed a review of the historical use of AFFF at the Site. Part of the review involved conducting a series of interviews with key Defence personnel (including present and former firefighters and support personnel) and members of the community. It is important to note that the information presented in the following sections were factual to the person(s) who contributed the information, however there may have been gaps in their knowledge or timeline of events. Potential historical source zones based on information outlined in the following sections are shown on **Figure 27** in **Appendix A**.

2.4.1 AFFF Formulations

AFFF formulations historically used at the Site contained a range of PFAS, including perfluorooctane sulfonate (PFOS) and perfluorooctanoic acid (PFOA). Between approximately 1976 and 2002/2003, the main AFFF product in use at the Site was 3M Lightwater™ which contained PFAS including PFOS and PFOA. For approximately the last 14 years Ansul's AFFF product Ansulite™ has been used in fire training exercises on the Site, it is noted that Ansulite™ is known to contain PFAS but only low concentrations of PFOS and PFOA (Airservices, 2016). It is also understood, based on analysis of Ansulite™ from other sites, that the product is likely to contain fluorotelomer surfactants which could

degrade to form various intermediate and perfluoroalkyl acid compounds. Since approximately July 2017 no fire training activities using AFFF have been conducted on the Site.

2.4.2 Fire Training Grounds and Other Training Areas

3M AFFF product Lightwater™ was brought into service with the Oshkosh P4 vehicles in 1976. 'HOT' fire training activities were conducted at the Former Fire Training Area using Lightwater™ as an extinguishing agent. Ignition sources used during the training included AVTUR, AVGAS, hydraulic oils, paints, thinners, tyres, paint stripper, unleaded fuel, diesel and solid combustibles.

The Former Fire Training Area was decommissioned prior to the 1988 Bicentenary Airshow, with the provision that a new fire training ground would be commissioned after the event. At the date of this report AECOM is not aware of any evidence that another formal fire training ground was ever commissioned. Additionally, adjacent the Former Fire Training Ground is a dis-used underground storage tank (UST) which was likely to have been installed during World War Two. Interviews indicated that the UST is likely to contain water and possibly AFFF residue.

'HOT' fire training was conducted between 1992 and 1995 opposite the access road to the Airfield Foam Cannon Testing Area. Interviews indicated that minimal AFFF was used.

'HOT' fire training has not occurred since 2001.

Interviews indicated that a fire training drill was conducted at Fuel Farm 2. AFFF was discharged onto all bulk storage tanks (Tanks 01, 02 and 03). During the drill, the Base's reserves of AFFF concentrate were depleted, it is estimated some 5,000-6,000 L of AFFF concentrate was discharged onto the tanks.

Base combatant Personnel Training was conducted at the rear of the Fire Section on a paved area. Training was reportedly conducted every week day, depending on the number of attendees, from approximately 1980 to 2002, using petroleum based fires and from 2002 onwards using an LPG burner. Two 10 L hand held extinguishers containing AFFF were used.

2.4.3 Emergency Response

On 15 October 1977 a departing United States Air Force C141 lost two engines during take-off on Runway 28. AFFF was utilised for internal fires and on Engines 3 and 4, which were external to the aircraft. This occurred at the intersection of the Runway and Taxiway Delta. The aircraft was subsequently towed and a AFFF cap was used to cover hydraulic oils and fuel which leaked from the aircraft.

In the approximate time period of 1983 to 1984, 50,000 L of AVTUR was spilled adjacent the Former Fuel Farm. Approximately 900 L of AFFF concentrate was sprayed onto both Rickabys Drop Zone and the Former Fuel Farm area. Additionally, 20L of concentrate was discharged into a drain where fuel was observed to be flowing.

Between 1976 and 2015, various aircraft landed at the Base which had fuel or hydraulic leaks. In these instances, an AFFF foam blanket was laid. Interviewees indicated these were not common occurrences.

In 2001, heavy winds during a storm caused a work stand to rupture the port wing fuel tanks on a C130J-30. AFFF was subsequently discharged onto parking positions 14 and 15.

Rosenbauer Panther tenders have on occasion shown a fault where foam is produced when only water agent is selected during section visit displays. These occurrences are considered to be rare and minimal foam was produced.

On 19 June 2005, firefighters from the Base responded to a factory fire in Mulgrave (approximately 5km SE of the Base). The Base's entire stock of Ansulite™ was used (5,500L) as requested by the then NSW Fire Brigades (now NSW Fire & Rescue).

2.4.4 AFFF Testing

Vehicle B AFFF testing on vehicles occurred weekly until the mid-2000s, when it became a monthly operation for on-line and serviceable off-line vehicles. During Vehicle B AFFF testing, it was indicated that up to 40 to 60 L of AFFF concentrate would be used per truck.

Between 1976 and 1988, Vehicle B AFFF testing occurred anywhere on the airfield. From 1992 to 1995, Vehicle B AFFF testing was conducted in the vicinity of the current location of the flying club. From 2001 to approximately July 2017, Vehicle B testing was conducted at the Airfield Foam Cannon Testing Area..

In approximately 1982/1983 the foam deluge system in Hangar 54 was used during acceptance testing, at the end of construction.

During the late 1980s through to the 1990s, AFFF may have been discharged from the foam deluge system associated with the Former Fuel Farm.

2.4.5 AFFF Storage

A total of 5,500 L of Ansulite™ concentrate is stored on the Site in the following locations (this does not include AFFF stored in deluge systems):

- 800L Ansulite™ AFFF Header Tank (Fire Section)
- Fire Section (drums of Ansulite™ AFFF concentrate)
- K Group (drums of Ansulite™ AFFF concentrate).

An additional 2000-3000L of AFFF concentrate is held in four storage tanks associated with the deluge system in Hangar 54.

Up to 1,500 fire extinguishers are stored on Base at any one time. Of these, approximately 400, 10 L extinguishers contain AFFF.

A minimum of 50 FL2.5 foam generators are located in workshops and aircraft hangars. Each FL2.5 holds up to 10 L of AFFF concentrate.

2.4.6 Fire Tenders

Various fire tenders have been in use historically at the Site, these include:

Airfield Crash Trucks

- 1970s – 1994. One International 1300 series Truck Fire Rescue (450 L AFFF concentrate capacity)
- 1978 – 1994. Four Oshkosh P4 (900 L AFFF concentrate capacity)
- 1994 – 2009. Four Triton (900 L AFFF concentrate capacity)
- 2009 – current Three Rosenbauer Panther (1300 L AFFF concentrate capacity).

Domestic Trucks

- 1970s – 1997. 1 x International 1800 series General Purpose Fire Truck (450 L AFFF concentrate capacity)
- 1997 – 2017. Four TITAN Spezialfahrzeugbau (400 L AFFF concentrate capacity)
- 2017 – current. Two Oshkosh Strikers (546 L AFFF concentrate capacity).

2.4.7 Other Information

Anecdotal information indicates that AFFF concentrate may have been discarded regularly across the grassed areas of the airfield. The quality of the AFFF concentrate contained in Oshkosh P4 fire tenders would be tested by refractometer readings each day. If the measurements did not meet specification, AFFF concentrate would be placed into drums to be used (recycled) in hand held extinguishers. If there were no drums available, the concentrate would be discarded onto the airfield. It was indicated to AECOM that up to 900 L could be discarded at any one time. Typically the AFFF concentrate would be discarded adjacent the Former Fire Training Area and the Former Fuel Farm. The interviewee identified that AFFF concentrate contained within the fire tenders would typically not meet specification at a frequency of approximately once per month while the Oshkosh P4's were in service (1978 to 1994).

Anecdotal information obtained by AECOM suggests that fire tenders would be sent for vehicle maintenance at the Mechanical Equipment Operations and Maintenance Section (MEOMS) area. Tenders would be sent with full tanks and be broken down for maintenance and rebuilt. Tenders would be returned with foam tanks 100% full after servicing, suggesting that AFFF concentrate contained in the tanks when the tender entered the MEOMS facility may have been discarded and replaced with new AFFF concentrate after servicing.

2.5 Water Use Survey

A Water Use Survey (the Survey) was distributed to the community in and around Richmond, Cornwallis and Windsor for the purpose of validating which exposure scenarios were applicable to receptors within the SA. The Survey was distributed to the community commencing 28 August 2017, a copy of the water use survey is provided in **Appendix K**. A total of 1,500 surveys were hand delivered to addresses within the SA, unless a mail box was unable to be found, stated no junk mail or the home owner identified they did not want to receive the survey at the time of delivery.

The community was provided multiple options for filing in the surveys. The Water Use Surveys were accessed by either download from the Defence website, distribution directly to residents via a letter drop (described above), completed during the community walk-in session or completed over the phone with AECOM's Communication Team.

The outcomes of the water use survey are discussed in **Section 4.1**.

2.6 Potential On-Site Sources of PFAS

The historic uses of AFFF at the Site (refer to **Section 2.4**) are likely to have resulted in primary and secondary sources of contamination at the Site. These are detailed in **Section 2.6.1** and **Section 2.6.2**.

2.6.1 Primary Sources

- AFFF use associated with the Airfield Former Fire Ground/Training Ground (Defence Contaminated Sites Register (CSR) Number: SW0247).
- AFFF use associated with the Airfield Foam Cannon Testing Area (CSR Number: SW002)
- AFFF use associated with aircraft accidents and other emergency response along the runway and taxiway
- AFFF spills/leakage during storage and handling at the Fire Station Building (CSR Number: SW0266)
- Potential discharge of AFFF from fire suppression systems at Hangar 54 and leakage from tanks storing fluids containing PFAS
- Potential AFFF use associated with Fuel Farm 2 (CSR Number: SW0249), and leakage from tanks storing fluids containing PFAS
- Potential AFFF use associated with Former Fuel Farm 1 (current Tanker Parking Area, CSR Number: SW003), and leakage from tanks storing fluids containing PFAS
- Potential discarding of AFFF concentrate associated with vehicle maintenance works in the MEOMS area (refer to **section 2.4.7**), note that no specific information describing the area where this would have taken place has been identified to date.

Given the history of AFFF use at the Site there may be additional former on-Site PFAS source zones such as aircraft hangars and emergency response locations where localised use of AFFF may have occurred. It is noted that, although a comprehensive AFFF history review was undertaken as part of the DSI, there is limited information available. These potential PFAS source zones are inferred to be smaller and less significant than the identified 'primary' and 'secondary' source areas but may still contribute additional PFAS mass and extent.

2.6.2 Secondary Sources

- Infiltration of surface water containing PFAS through unlined swale drains to underlying soil and groundwater
- Leakage or overflow of water containing PFAS at the TWP (CSR Number: SW0263) and leakage from the trade waste drainage network. Infiltration of water containing PFAS at the STP (CSR Number: SW0057) in pipelines leading to the sewage treatment plant and at the associated effluent lagoons
- PFAS impacted soil in the aquifer zone
- PFAS impacted shallow soil from surface run off/flooding
- PFAS impacted sediments in drains.

2.7 Potential Off-Site Sources of PFAS

A number of potential off-Site sources of PFAS have been identified, as outlined in **Table 10** below and **Figure 30** in **Appendix A**.

Table 10 Potential Off-Site Sources of PFAS

Potential Source	Location	Notes
Wastewater Treatment Plants	North Richmond	Direct discharge of treated effluent to Hawkesbury Nepean River System
	Wallacia	
	Winmalee	
Water Recycling Plants	Picton	'Precautionary' discharge or discharge of excess to Hawkesbury Nepean River System
	West Camden	
	Penrith	
	Richmond	
Fire and Rescue NSW	Cranebrook Fire Station	0.4 km west of the headwaters of Rickabys Creek
	Richmond Fire Station	1.0 km west of Site
	Windsor Fire Station	0.2 km south of Hawkesbury River
	South Windsor Fire Station	0.8 km east of Rickabys Creek
	Regentville Fire Station	1.4 km east of Nepean River
	Penrith Fire Station	2.0 km east of Nepean River
TestSafe and Fire and Rescue NSW	Londonderry	Within Rickabys Creek catchment, 0.8 km east of the creek. Active PFAS investigation. PFAS detections reported in NSW EPA (2016). Surface water and soil sampling have been carried out however, no results of this investigation have been made publicly available at the time of writing.
Recycled Water Use Areas	UWS Campus	Irrigation of approximately 180 ha. Usage rate unknown
	Richmond Golf Course	Irrigation on course. Usage rate approximately 90 ML/year
	Windsor Golf	Irrigation on course. Usage rate unknown

Potential Source	Location	Notes
	Course	
Paper Manufacturer	Windsor	Paper manufacturer in Windsor potentially within the Rickabys Creek catchment
Factory Fire	Mulgrave	5,500L of Ansulite™ supplied from RAAF Base Richmond to F&R NSW.
Waste Facilities	South Windsor	0.3 km west of Rickabys Creek
	Londonderry	Closed landfill approximately 2 km west of Rickabys Creek and 3 km east of the Hawkesbury River

2.8 Site and Contaminant Characteristics and Limitations of Environmental Investigation

This section describes the aspects and interactions of the Richmond and Windsor environment that are relevant to the investigation of the nature and extent of PFAS compounds.

An overview of the characteristics of the physical environment and PFAS impact that have been considered in developing the approach to the DSI (including refinement of the CSM and understanding of potential exposure scenarios as data have been generated) are discussed in **Table 11**, and following sections.

The data presented in this report are considered to be appropriate to meet the objectives of the DSI, (the DQO are presented in **Section 1.6** and Data Validation is presented in **Appendix J**) but must be interpreted with reference to:

- Environmental aspects and characteristics
- PFAS migration
- Chemical properties of PFAS
- PFAS analysis and data interpretation issues
- Data characteristics and uncertainties (refer to **Section 2.11**).

Table 11 Environmental Aspects and Characteristics

Aspect	Characteristics and Consideration for Environmental Investigation	Investigation Strategy
<p>Scale of SA and inherent complexity of PFAS and the evolution of knowledge</p>	<p>The SA covers an area of more than 16 km² of terrestrial environment and considers multiple media, including soil, sediment, groundwater and surface water.</p> <p>AFFF contains a broad range of PFAS in different forms (cationic, anionic and zwitterionic), only some of which are currently known. For the DSI, up to 28 PFAS compounds (refer to Table 1) were able to be identified and quantified by analytical laboratories, and this list is being progressively expanded and lower limits of detection reduced. The behaviour of different PFAS compounds vary in the environment. For instance, they are transported at different rates and by different mechanisms within the different media, and sorption to soil minerals and organic carbon is variable. Research into these differences is ongoing.</p>	<p>As with any contamination investigation, interpolation and interpretation between widely spread and sometimes sparse data points has been undertaken in order to better understand the nature and extent of PFAS within and beyond the SA, and to inform the subsequent HHRA and ERA.</p> <p>The DSI was designed to provide an understanding of the overall extent of PFAS compounds within the SA and in the media selected. The objective of the data set was not to calculate future remediation areas and volumes in each type of media investigated.</p>
<p>Source distribution, environmental complexity and interactions</p>	<p>PFAS sources PFAS from the Site is inferred to be associated with multiple primary and secondary source areas within the Site (refer to Section 2.6). The occurrence, timing, exact location, formulation, and mass of PFAS that was historically discharged at these source areas were not accurately recorded and, therefore, all potential sources may not have been identified. As a result, there has been a reliance on anecdotal information.</p> <p>These source areas have generated groundwater impacts and in some instances, surface water impacts, which extend off-Site across the eastern, northern and western boundaries.</p> <p>Groundwater movement Groundwater on the Site, in the highly permeable Clarendon Formation Aquifer (CFA), migrates to the north-east and flows into the Lowlands Formation Aquifer (LFA). The movement of water and</p>	<p>Soil, groundwater, surface water and sediment sampling was undertaken to characterise soils, geology, hydrogeological conditions.</p> <p>Monitoring wells were installed on- and off-Site (particularly concentrated in the area to the north east of the Site and to improve understanding of flow to the north</p>

Aspect	Characteristics and Consideration for Environmental Investigation	Investigation Strategy
	<p>associated PFAS compounds in the CFA and LFA is influenced by varying permeability at different depths (including the presence of the silts, clays and gravels), as well as by the depths of underlying bedrock and interactions with man-made drains and Creeks on the Lowlands. The groundwater system is dynamic and groundwater may discharge to and interact with a complex surface water drainage system. Further, rainfall events and the irrigation on and off-Site may have also influenced the distribution/migration of the contamination.</p> <p>Surface water movement Surface water drainage, which also carries PFAS within the Site and throughout the SA, is complex. Surface water runoff from the Site discharges to the north adjacent the STP, from the south east into Rickabys Creek and from the STP to Bakers Lagoon. All surface water flows from the Base ultimately enter the Hawkesbury River.</p> <p>PFAS migration between media The behaviour of PFAS within a dynamic environment in terms of transport within and between media is complex and subject to the influence of a number of climatic drivers, hydrologic responses and the nature of the PFAS. Such influences include natural factors such as fluctuations in groundwater levels, surface water flows in response to rainfall, as well as man-made influences, such as groundwater pumping and surface flow modification through installation of flow control structures. Wherever possible, these characteristics have been considered in planning the investigation and in interpretation of the results.</p> <p>Additionally, on a micro scale, the geochemical and geophysical nature of the media is variable across the SA and at present plays a relatively minor part in developing understanding and immediate management of risk. Understanding these factors may carry greater importance at a later date when management and/or remediation actions are being designed (if required).</p>	<p>east) across the SA, and surface and groundwater elevations were measured to understand the groundwater flow regime.</p> <p>Surface water sampling locations were selected to capture run off from the Base as well as downstream within creeks and drains, and the Hawkesbury River. Background samples were also collected upstream in drains, Rickabys Creek and the Hawkesbury River</p>

Aspect	Characteristics and Consideration for Environmental Investigation	Investigation Strategy
<p>Time period of PFAS discharge and environmental investigation</p>	<p>Time period of PFAS discharges It is inferred that PFAS compounds have been occurring and migrating via surface water and groundwater from circa 1976. The extent of PFAS identified in the SA reflects the cumulative discharges influenced by natural and man-made processes over that time. It is noted that the chemical constituents of AFFF have changed many times over the last 40 years. As such, retrospectively understanding the composition of AFFF and the amount of different PFAS compounds over time is extremely difficult.</p> <p>Time period of DSI The DSI has been undertaken over a relatively compressed time period (approximately August 2017 to January 2018).</p> <p>It is stressed that the data presented in the DSI represent a 'snapshot' of the conditions at that point in time, and may vary over time. This is discussed further in Section 2.11.</p>	<p>In order to expedite the DSI, multiple investigation tasks (e.g. soil sampling, surface water and sediment sampling, hydrogeological investigations, groundwater sampling etc.) were undertaken in parallel, rather than a conventional sequential process. This has limited the opportunity to optimise some aspects of the investigation program, such as seasonal variability.</p> <p>There is an opportunity for long-term trends in PFAS movement or concentrations to be assessed following the development and implementation of the PMAP, as additional data are collected and compared to data from the historical and current investigations.</p>
<p>PFAS behaviour</p>	<p>Some of the environmental processes and interactions that are potentially significant to the understanding of PFAS fate and transport are affected by the chemical properties of PFAS compounds. These include: moderate to high solubility in fresh water; sorption and desorption to aquifer solids, organic carbon and sediments within surface water drains; resistance to degradation; and accumulation within ecosystems. Some longer-chain PFAS are considered to be precursors to PFOS and PFOA and could potentially degrade and add to the concentration of PFOS and PFOA identified within the environment.</p> <p>Important characteristics of PFAS compared to most other forms of chemical contamination include: resistance to breakdown; solubility; high environmental mobility; and propensity to occur in, and migrate, in a wide range of environmental media including soil, sediment, concrete, surface water, groundwater and biota; including in vegetation, and bioaccumulation in fish and birds.</p>	<p>The DSI included a preliminary field based assessment of PFAS sorption to aquifer material where PFAS was detected in groundwater samples. Additional data was collected including TOC and CEC data for soils and sediment provide greater understanding of PFAS fate and transport.</p>

Aspect	Characteristics and Consideration for Environmental Investigation	Investigation Strategy
Access limitations	Some locations within the SA that could have yielded useful information were not accessible for sampling. Reasons for the lack of access were due to landowner consent not being obtained.	Wherever possible, proposed but inaccessible sampling points were relocated to the closest alternative location.
Interpretation of data variability	<p>The characteristics of the natural and man-made systems discussed above means that environmental data collected during the DSI are subject to potentially significant and frequent changes in concentration.</p> <p>The DSI was intended to further assess the current extent of PFAS impact and to provide additional data for human health and environmental risk assessment (the 2018 HHRA and the 2018 ERA are currently in preparation).</p> <p>The data reported are by necessity a 'snapshot' in time and should not be regarded as an indication of static or long-term conditions. It is anticipated that the conditions described at individual sampling points may change with time in response to environmental processes and man-made influences.</p>	The potential for variability in PFAS concentrations and distribution has been considered conservatively when assessing the extent of impact described in this DSI Report.

2.9 PFAS Characteristics

2.9.1 Key PFAS Migration Processes

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

Identified key migration processes for PFAS affected water include:

- The groundwater system (vertically and laterally, primarily via the Clarendon Formation Aquifer on-Site and the Lowlands Formation Aquifer off-Site)
- Surface water drainage lines in the form of piped networks and open, unlined, channels (on- and off-Site)
- Trade waste network (influent on- and off-Site).

Some PFAS leach from soils and pavements under neutral water conditions. Consequently, the infiltration of water through the soil profile may mobilise some PFAS adsorbed onto and situated within the pore spaces of soil particles (although the rate of mobilisation can be impacted by the soil chemistry and the PFAS chain length and ionic composition). PFAS precursors may also degrade to generate PFOS and PFOA and other shorter chained PFAS in certain physiochemical environments down-gradient of identified sources.

2.9.2 Physical and Chemical Properties of PFOS, PFOA and PFHxS

The five general processes used to describe the fate and transport of contaminants in groundwater (Domenico and Schwartz, 1990) are:

1. Advection – transport in groundwater flow
2. Diffusion – molecular diffusion in aquifer, independent of flow
3. Dispersion – hydrodynamic spreading of contaminant
4. Adsorption and desorption
5. Degradation – biodegradation of long-chain fluorocarbons.

Some PFAS appear to have little contaminant transport retardation (i.e. adsorption or degradation) based on the extent of the observed contaminant plume and properties of identified PFAS. This is likely the result of the hydrophilic properties (affinity for water) of the functional end groups of some PFAS. These and other physiochemical properties will, in some instances, prevent PFAS from adsorbing to most soil particles. An exception to this is some metal oxyhydroxides (Gao and Chorover 2012) and organic carbon (Zareitalabad et al. 2013) which have been shown to increase sorption of PFOS and PFOA.

Biodegradation of PFOS and PFOA has not been observed, although breakdown of longer chain 'precursor' PFAS compounds (including perfluorinated carboxylates and sulfonates) can lead to PFOS, PFOA and PFHxS formation.

As PFAS are being transported with water, the concentrations will generally decrease with distance due to the processes of advection, diffusion and dispersion. The environmental fate of the PFAS contaminant mass is expected to be significantly influenced by groundwater movement, extraction and surface water drainage away from a source.

While data are limited, based on a literature review, it is generally considered that PFOS, PFOA and PFHxS are persistent contaminants in the environment, and PFOS has been listed as a persistent organic pollutant (POP) under Annex B of the Stockholm Convention since 2009.

A fact sheet, developed by the US Environmental Protection Agency's Federal Facilities Restoration and Reuse Office (FFRRO) (2014), provides a brief summary of the physical and chemical properties of PFOS and PFOA. The summary is reproduced in **Table 12** below. AECOM has also included physical and chemical properties for PFHxS, derived from publically available publications.

Table 12 Physical and chemical properties of PFOS, PFOA and PFHxS

Property	PFOS	PFOA	PFHxS
CAS Number	2795-39-3	335-67-1	355-46-4
Physical description (physical state at room temperature and atmospheric pressure)	White powder	White powder/waxy white solid	White crystalline powder
Molecular weight (g/mol)	538 (potassium salt)	414	400.12
Water solubility (mg/L at 25 °C)	570 (purified), 370 (freshwater), 25 (filtered seawater)	9.5×10^3 (purified)	2.3×10^3
Melting point (°C)	> 400	45 to 50	272-274
Boiling point (°C)	Not measurable	188	114.7
Vapour pressure at 20 °C (mm Hg)	2.48×10^{-6}	0.017	0.442
Air water partition coefficient (Pa.m ³ /mol)	$< 2 \times 10^{-9}$	Not available	-2.38
Octanol-water partition coefficient (log K _{ow})	Not measurable	Not measurable	5.17
Organic-carbon partition coefficient (log K _{oc})	2.57	2.06	1.78
Henry's law constant (atm m ³ /mol)	3.05×10^{-9}	Not measurable	Not measurable
Half-life	Atmospheric: 114 days Water: > 41 years (at 25° C) Photolytic: > 3.7 years Sonolysis: 20 to 63 minutes	Atmospheric: 90 days Water: > 92 years (at 25° C) Photolytic: > 349 days Sonolysis: 20 to 63 minutes	Atmospheric: 76.4 days Water: no data Photolytic: negligibly degraded via photolysis Sonolysis: no data

Notes: g/mol – grams per mole; mg/L – milligrams per litre; °C – degree Celsius; mm Hg – millimetres of mercury; Pa m³/mol – pascal-cubic metres per mole; atm m³/mol – atmosphere-cubic metres per mole

Sources: ATSDR 2009; Brooke et al. 2004; Cheng et al. 2008; EFSA 2008; US EPA 2002; UNEP 2006; FSANZ (2017); Wang et al. 2011; European Chemicals Agency, 2015

Literature values for solubility (in purified water) for PFOS and PFOA are 570 mg/L and 9,500 mg/L, respectively (US EPA, 2014). However, the solubility of PFOS decreases in natural waters that contain high amounts of dissolved solids such that the solubility of PFOS in salt water is approximately 25 mg/L. The solubility of PFOA in water is higher than PFOS.

Literature values for the soil organic carbon-water partition coefficient (Log KOC) for PFOS and PFOA are approximately 2.57 and 2.06, respectively (US EPA, 2014). The soil organic carbon-water partitioning coefficient is the ratio of the mass of a chemical that is adsorbed in the soil per unit mass of organic carbon in the soil per the equilibrium chemical concentration in solution. KOC values are useful in predicting the mobility of organic soil contaminants; higher KOC values correlate to less mobile organic chemicals, while lower KOC values correlate to more mobile organic chemicals. In this regard, the literature values of KOC suggest that PFOS is less mobile than PFOA (although it is recognised that use of literature KOC values can lead to under or over estimation in the natural environment).

2.9.3 PFAS Analysis and Data Interpretation Issues

The following points provide an overview of some of the issues that have been considered in validating analytical results and interpreting the results of environmental testing.

- Accurate analytical techniques for identifying and quantifying PFAS are relatively new. The USEPA standard method was published in 2009 and Australian NATA certified commercial analysis services also became available in 2009.
- Analytical proficiency in Australia is continuing to improve, with limits of detection lowering and the range of detectable PFAS increasing. The use of laboratory standard reference materials has also been improved to better address issues including the quantitation of linear and branched PFAS compounds. As a consequence, some differences in analysis results can be expected when sample locations are retested using more recent analytical techniques or where samples are split (for quality control purposes) between different laboratories. These issues are considered in the data quality assurance and data validation processes that have been used in the investigation (refer to **Table 3** in **Section 1.6.7**).
- Differences in sampling methods – Over the course of the DSI, groundwater has been sampled by two different low flow methods including: bladder pump and peristaltic pump (excluding BW001 where a windmill was used to draw water from the bore and a grab sample was collected from the outlet). These different methods could introduce additional PFAS concentration variability between locations or from the same locations over time.
- Low screening concentrations - At sub part-per-billion (ppb) and part-per-million (ppm) concentrations, very minor changes on environmental conditions can lead to seemingly large relative differences in PFAS results between adjoining sample locations or in repeat sampling events. However, the actual concentration differences may only be very small in terms of absolute concentrations.
- Fluctuation of results and long-term trends at individual testing locations - It will take repeated sampling of individual monitoring wells or surface water sampling locations over time (potentially years) to develop an understanding of the range of typical variations in concentration and longer term trends (if any).
- Different analytical methods for different media - PFAS have been detected as being present in almost all media tested within the SA including soil, sediment, surface water and groundwater. It is noted that different media (soil/sediments, waters, etc.) all have different sample preparation and analysis processes.
- Background concentrations and cross contamination - The widespread use of PFAS in industrial processes and products (including manufacture of water and grease resistant coatings, metal plating, paints, cement additives, food packaging and numerous other applications [US EPA, 2017]) over decades and its resistance to breakdown in the environment, means PFAS are being detected throughout the environment and in human blood serum from sources other than AFFF usage. Consequently, there is a potential for PFAS cross contamination of samples (e.g. from the Teflon liners in sample container lids, Teflon tubing often used in groundwater sampling – it is noted that these items were not used during the DSI) that must be controlled to reduce the potential for false positive results .

2.10 Previous Investigations

2.10.1 Noel Arnold and Associates, 2011

Noel Arnold and Associates, 2011 presented a limited amount of data relating to PFAS impacts at the Site. A summary of this data is provided below. (Refer to the Noel Arnold and Associates, 2011 report for specific sample and facility locations).

Groundwater

There are limited data for PFAS in groundwater on-Site (RAAF Base Richmond and Rickabys Drop Zone). Samples were collected from the following locations:

- SW0003 (Tanker Parking Area – Former Fuel Farm 1), PFOS concentrations ranged from 0.70 µg/L to 15.00 µg/L, and PFOA concentrations ranged from 0.17 µg/L to 0.82 µg/L
- SW0061 (Area 102), PFOS concentrations ranged from 0.27 µg/L to 11.00 µg/L, and one PFOA result reported a detection of 0.29 µg/L
- SW0138 (Area 8), PFOS concentrations ranged from non-detect to 0.19 µg/L
- SW238 (Building 54), PFOS was detected at a concentration of 0.1 µg/L.
- SW0249 (Fuel Farm 2), PFOS concentrations ranged from 0.09µg/L to 1.60 µg/L, and one sample reported a PFOA concentration of 0.12 µg/L
- SW0257 (Weirs and surrounding Floodplain), PFOS concentrations ranged from 0.97 µg/L to 84 µg/L, and PFOA concentrations ranged from non-detect to 0.61 µg/L.

The report presents no data relating to PFAS presence in groundwater at off-Site locations.

Surface Water

The report does not present any surface water data on or off-Site.

Sediment

There is a limited data set for PFAS in sediment at on-Site locations. Samples were collected from the following locations:

- SW0257 (Weirs and surrounding Floodplain), PFOS concentrations ranged from 0.010 mg/kg to 0.060 mg/kg.

The report presents no data relating to PFAS impacts in sediment at off-Site locations.

Soil

There is limited data for PFAS in soil on-Site. Samples were collected from the following locations:

- SW0002 (Airfield Foam Cannon Testing), PFOS concentrations ranged from 0.0091 to 0.360 mg/kg, and PFOA ranged from 0.0017 to 0.370 mg/kg
- SW0138 (Area 8), PFOS concentrations ranged from non-detect to 1 mg/kg, and PFOA ranged from non-detect to 0.0034 mg/kg
- SW0238 (Building 54), PFOS concentrations ranged from non-detect to 0.0025 mg/kg
- SW0247 (Fire Training Ground), PFOS concentrations ranged from 0.0044 to 1.1 mg/kg, and PFOA ranged from non-detect to 0.11 mg/kg
- SW0257 (Weirs and surrounding Floodplain), PFOS concentrations ranged from non-detect to 0.015 mg/kg, and PFOA concentrations ranged from non-detect to 0.0041 mg/kg
- SW0258 (Rickabys Creek and Rickabys Creek Tributary), PFOS concentrations ranged from non-detect to 0.048 mg/kg
- SW0266 (Fire Station Building 291), PFOS concentrations ranged from non-detect to 1.6 mg/kg, and PFOA concentrations ranged from non-detect to 0.32 mg/kg.

The report presents no data relating to PFAS impacts in soil at off-Site locations.

Summary of Noel Arnold and Associates (2011) in the context of the DSI works

Noel Arnold and Associates (2011) reported the presence of PFAS at the Site in multiple media. No laboratory reports were included in the report which displayed PFAS results and no PFAS results were included in the groundwater summary table. Therefore no conclusion can be made on the reliability of the data, however the surface water and sediment results reported were used to guide sampling locations targeted during the EWP.

2.10.2 GHD, 2016

GHD collected groundwater and surface water samples off-Site, including publicly accessible locations and private properties (the exact locations were not disclosed) that surround the Site. A summary of this data is provided below.

Groundwater

Two existing groundwater monitoring wells were sampled to the south of the Site (RCH_GW001 and RCH_GW059155). Both samples reported PFAS concentrations less than the Limit of Reporting (LOR).

Surface Water

Nine surface water samples were collected from off-Site locations. In summary:

- PFOS concentrations ranged from <0.01 µg/L to 0.08 µg/L
- PFOA concentrations were less than the laboratory LOR
- The sum of PFOS + PFHxS concentrations ranged from <0.015 to 0.14 µg/L.

Summary of GHD, 2016 in the context of the DSI works

Monitoring wells RCH_GW059155 and RCH_GW001 are located up gradient of wells located adjacent the base boundary, in particular MW42 and MW43.

The majority of GHD's surface water samples were collected on private properties (5 of 9 samples). This was because either GHD was unable to locate groundwater bores on these properties or no location data was included in the GHD, 2016 report. The remaining samples were collected from within Rickabys Creek.

2.10.3 Jacobs, 2016

In-situ soil sampling of areas potentially impacted by AFFF was undertaken to a maximum depth of 0.5 m bgs. The works were associated with upgrade of the on-Site swale drainage system.

A total of 30 soil samples were collected. In summary:

- PFOS concentrations ranged from 0.0091 mg/kg to 59.4 mg/kg
- PFOA concentrations ranged from 0.0005 mg/kg to 5.38 mg/kg
- The maximum leachable concentration of PFOS reported as 3080 µg/L (after toxicity characteristic leaching procedure was performed).

Excavated soils are currently stored in temporary plastic lined stockpiles on-Site.

2.10.4 Other Environmental Investigations

AECOM has reviewed a number of environmental investigation reports prepared for the Site which are summarised in **Appendix C**.

2.11 Data Characteristics and Uncertainties

The DSI and subsequent risk assessment processes involve a range of interpretation and assumptions regarding human activity, site conditions, contaminant behaviour and natural processes. These assumptions are based on-Site-specific information (where available). However, it is not always possible to fully characterise or predict site conditions and human activities at a site for the exposure period considered.

The data that have been collected provide a basis for improved understanding of the nature and extent of PFAS compounds when interpreted with reference to the natural processes that are occurring at the time and the types of variability that can be expected. This is summarised in the CSM in **Section 6.0**.

Conservative (i.e. likely to over-estimate actual conditions) assumptions have been made in the presentation of data (on figures, tables and as part of the CSM) based on the available information to reduce the potential for underestimation of the extent or concentration of impacts.

The nature and extent of contamination presented in this report is not intended to be a definitive description. Rather, it is 'snapshot' of conditions as encountered when the samples were taken during the DSI. Understanding of the nature and extent of contamination will continue to evolve as additional data are collected that expands the spatial coverage and provides a greater understanding of the temporal variability of concentrations. **Table 13** summarises some of the characteristics of the data that have been presented in this report, how temporal and other forms of variability may affect interpretation of the data and the steps taken to minimise the impacts of this variability on the resultant conclusions. These factors have also been considered in presenting data (on figures, tables and as part of the CSM) within this report.

It is also noted that data used for specific purposes, such as in the 2018 HHRA (in preparation) or the 2018 ERA (in preparation), are also subject to a task-specific data uncertainty evaluation (not included in this report) with conservative assumptions adopted to address the identified uncertainties.

Table 13 Identified forms of variability in the data and strategies to reduce variability

Data Set	Natural and other Variability, Local Environmental Processes <i>Potential for change in values</i>	Investigation Strategy	Interpretation Strategy and Significance to Objectives
<p>Groundwater elevations and potentiometric surface contours</p> <p>Figures 11 and 11B Appendix A</p>	<ul style="list-style-type: none"> Rainfall and infiltration, flooding and standing water. Pumping of surface water for irrigation (e.g. from the Hawkesbury River or Bakers Lagoon) has the potential to locally increase groundwater levels. Groundwater levels have the potential to vary according to environmental conditions. Such changes would normally be evident over days to weeks but could occur faster in response to rainfall events. 	<ul style="list-style-type: none"> Collection of water levels across the majority of the SA over as short a period as possible (e.g. groundwater elevations for DSI were measured on 21 November 2017). Collection of short- and medium-term weather data (rainfall etc.). 	<ul style="list-style-type: none"> While groundwater levels are subject to fluctuation, the overall gradients and flow directions established from the data are considered to be sufficient for the purpose of the DSI.
<p>Soil and sediment analysis results</p> <p>Soil: Figures 13 to 15 in Appendix A</p> <p>Sediment: Figures 25 to 27 in Appendix A</p>	<ul style="list-style-type: none"> Lateral distribution of AFFF at time of use gives rise to poorly defined impact areas Leaching of PFAS by rainwater, surface water, flooding, erosion and deposition, excavation and filling etc. The lateral and vertical distribution of PFAS in soil and sediment samples is potentially extensive, occurs at widely varying concentrations and is subject to variation over relatively short distances and depths but is expected to be relatively stable over time. 	<ul style="list-style-type: none"> Collection of soil samples across the SA to characterise but not define lateral and vertical extent. Collection of sediment samples from sediment/water interface in drains to assess potentially mobile materials. 	<ul style="list-style-type: none"> The data collected have provided the necessary understanding of surface areas to support the CSM. The data collected are considered to be sufficient for the purpose of the DSI.

Data Set	Natural and other Variability, Local Environmental Processes <i>Potential for change in values</i>	Investigation Strategy	Interpretation Strategy and Significance to Objectives
<p>Groundwater analytical results</p> <p>Figures 19 to 22 in Appendix A</p>	<ul style="list-style-type: none"> • PFAS migration • Infiltration of rainwater / seasonal conditions • Low precipitation conditions • Irrigation and other pumping / abstraction • Well construction / screened interval depths • Sampling methods (low flow vs 'first flush'), different sampling techniques for groundwater wells and residential bores • Groundwater PFAS concentrations have the potential to change significantly although less rapidly than surface water. In particular, it is possible that dilution may occur following rainfall events, (potentially within hours), particularly during high surface water runoff events. 	<ul style="list-style-type: none"> • Sampling of DSI groundwater wells followed industry standards including well development and purging • Sampling of groundwater abstraction bores on privately owned lane utilised a 'first flush' technique to better reflect potential human exposure conditions at point of water use 	<ul style="list-style-type: none"> • It is possible that different sampling protocols between groundwater monitoring wells and abstraction bores may have resulted in slightly different results • It is considered unlikely that these differences would have had a significant impact on the evaluation of the nature and extent of PFAS impact in groundwater • The groundwater data collected are considered to be sufficient for the purpose of the DSI.
<p>Surface water analytical results</p> <p>Figures 22 to 24 in Appendix A</p>	<ul style="list-style-type: none"> • Rainfall – seasonal trends (e.g. drought) and short-term events (e.g. flooding) • Tidal interactions in the Hawkesbury River • Gaining / losing stream conditions (i.e. groundwater inflow to drain) • Pumping, diversion, construction dewatering • Surface water conditions change over hours. <p>Surface water PFAS concentrations have the potential to change rapidly (potentially in hours), particularly during runoff events.</p>	<ul style="list-style-type: none"> • Collection of samples throughout potentially impacted on- and off-Site drainage and Creek network • Collection and reporting of climate data throughout investigation period • Collection of field parameters to facilitate characterising water type. 	<ul style="list-style-type: none"> • Clarify that data represent conditions at time of monitoring • Interpret results in context of local processes and recent rainfall or flow events • It is considered unlikely that these differences would have had a significant impact on the evaluation of the nature and extent of PFAS impact in surface water • The surface water data collected are considered to be sufficient for the purpose of the DSI.

Data Set	Natural and other Variability, Local Environmental Processes	Investigation Strategy	Interpretation Strategy and Significance to Objectives
<p>Illustrated groundwater extent of PFAS</p> <p>Figure 28 in Appendix A</p>	<p><i>Potential for change in values</i></p> <ul style="list-style-type: none"> The interaction of natural processes as discussed at Section 2.3 analytical variability as discussed in Section 2.11 and characteristics of the data collected is described above Any illustrations of extent of PFAS in groundwater are by necessity a simplification of complex environmental interactions and can only be a snapshot in time that is subject to review as additional data becomes available. 	<ul style="list-style-type: none"> Review the data collected during the DSI at each sampling point and typically adopt maxima in plume interpretation to avoid false negatives Conservatively interpret plume extent where impacted well is surrounded by clean wells. That is, outliers are not ignored Interpretation of extent of impact will involve available data. 	<ul style="list-style-type: none"> It is noted that the current groundwater conditions are the result of long term PFAS migration and interaction with natural systems. While short-term variability is likely, it is inferred that the overall extent of impact is unlikely to significantly change in the short term (e.g. over months) The contoured PFAS concentration data is conservatively illustrated based on the maximum concentrations detected at any of the relevant data points Contouring of the data may illustrate areas as being affected with PFAS when some groundwater data suggests concentrations below the laboratory LOR, or lower concentrations

3.0 Approach and Methodology

3.1 Sampling Rationale

3.1.1 SAQP

AECOM's approach to deliver the DSI was comprised of methodologies described in the DSI SAQP (AECOM, 2017a) and reviewed by the Site Auditor and NSW government agencies. In accordance with Guidance Document D and the DSI SAQP, non-PFAS CoPC were sampled during the DSI however are not discussed in this report. Results of non-PFAS CoPC are provided in **Appendix M**.

3.1.2 Sampling Rationale

The sampling rationale for the DSI is detailed in the DSI SAQP and in **Table 14** below. Sample locations sampled as part of the EWP and DSI are presented in **Figure 6** in **Appendix A**.

Table 14 Sampling Rationale

Task	Field Activities	Approach and Rationale
Groundwater monitoring and hydrogeology	Monitoring well location selection and sampling	<p>On-Site two monitoring wells were installed on Rickabys Drop Zone, hydraulically downgradient of existing monitoring wells which reported detections of PFAS during the EWP.</p> <p>Off-Site locations were chosen to assess the extent of PFAS in groundwater in the SA, particularly across Cornwallis (hydraulically down gradient of the site). Sampling was completed on a total of 24 new monitoring wells/bores and two identified residential bores.</p>
	Slug testing	<p>Slug tests of 8 selected monitoring wells considered representative of the aquifer were completed to enable an estimation of the hydraulic conductivity. These results were used in conjunction with published conductivity data to aid the assessment of groundwater flow velocity.</p> <p>Wells selected for slug testing were chosen to provide hydraulic conductivity estimates with an appropriate spread across the SA, and from different geological units within the Lowlands Formation and the Clarendon Formation.</p>
	Gauging events	To assess groundwater elevation in the SA, two gauging events were completed on pre-existing monitoring wells in July 2017 and selected pre-existing and newly installed monitoring wells in November 2017, as per the SAQP. An additional data gap gauging event was conducted in May 2018. The groundwater elevation and survey data were used to interpret the groundwater flow directions and compare with previous reported data from the Site.
	Saturated zone soils	<p>Saturated zone soils were collected from each borehole to assess soil characteristics. Ten samples were analysed for:</p> <ul style="list-style-type: none"> • Organic Carbon • Cation Exchange Capacity • Total Iron <p>In addition, seven mid screen soil samples paired with a groundwater detection were analysed for PFAS to generate an estimate of sorption to aquifer solids under field conditions.</p>
	Unsaturated zone soils	Soil samples were collected from the unsaturated zone within across the SA to assess the extent of PFAS impacts in the vadose zone (i.e. above the water table), and to provide data for the 2018 HHRA and 2018 ERA.
	Particle size distributions (PSD)	Seven soil samples were analysed for particle size distribution analysis to confirm observations during field logging and for estimation of the porosity.
	Soil – non-PFAS suite analyses	Locations were selected in accordance with Department of Defence (2017c) Guidance Document D – Non PFAS Analysis of Other Chemicals of Potential Concern, March 2017.

Task	Field Activities	Approach and Rationale
Groundwater sample analysis	Groundwater PFAS suite analyses	All existing and newly installed groundwater monitoring wells that were sampled were analysed for the extended PFAS suite to develop an understanding of the PFAS compounds and concentrations present in the SA.
	Groundwater – major cations and anions	Samples were analysed from 89 monitoring well locations and 1 residential bore to characterise the chemistry of the waters and assist with further understanding connectivity between surface water and groundwater.
Surface water and sediment investigation	Surface water and sediment sampling	<p>A total of 18 surface water samples were collected from new locations off-Site. Sample locations were selected to generate a dataset that would include waters not regarded to have been influenced by the Base (background), and within the receiving drains, Rickabys Creek and the Hawkesbury River.</p> <p>Additionally, 12 locations on and off-Site were resampled following a rainfall event, due to prolonged dry conditions. sampling took place outside of the DSI fieldworks timeframe and is reported in Appendix L. The specific location of the samples will be selected based on field observations and will be targeted towards on-Site locations with known PFAS presence, off-Site discharge points, receiving drains, Rickabys Creek and the Hawkesbury River. The purpose of these locations is to further investigate potential PFAS presence in surface water both on and off-Site.</p>

3.2 Methodology

Due to the ubiquity of PFAS used in a variety of everyday products and the potential for cross contamination during sampling activities, the recommended mitigation practices identified in the interim guidance document on the assessment and management of PFAS, published by Western Australia's Department of Environmental Regulation (January 2017) were implemented during the sampling program.

During the sampling program the Site Auditor was invited to observe the implementation of the sampling methodologies described in the sections below and no issues were reported.

The adopted sampling methodologies are summarised in the following sections.

3.2.1 Soil

Table 15 Soil Investigation Methodologies

Activity	Details
Service clearance	The borehole locations were checked for underground services by a Telstra accredited service locator using radio-detection and/or Ground Penetration Radar. Reference was made to utility plans obtained through the Dial-Before-You-Dig service and plans obtained from the Department of Defence.
Drilling method to retrieve soil samples and/or advance hole for monitoring well installation	<p>Boreholes were initially cleared by hand auger or Non Destructive Drilling (NDD) to a depth of approximately 1.5 m bgs and 250 mm diameter to minimise the risk of contact with underground services.</p> <p>Lowlands Formation: Push tube method was used from 1.5 m bgs to provide relatively undisturbed samples appropriate for accurate logging of subsurface conditions. Push tube drilling was followed by hollow stem auger drilling to a minimum depth of 5.0 m bgs (MW96) and maximum depth of 23.0 m bgs (MW92).</p> <p>Clarendon Formation: Sonic drilling method was used from 1.5 m bgs to provide relatively undisturbed samples appropriate for accurate logging of subsurface conditions. Sonic drilling proceeded to a minimum depth of 15.5 m bgs (MW75) and maximum depth of 24.0 m bgs (MW80).</p>
Soil logging	Soil logging was in general accordance with the Unified Soil Classification System (USCS).
Soil sample collection	Soil samples were collected directly from the hand auger, push tube cores or hollow stem auger flights by gloved hand and placed into laboratory-prepared 250 mL plastic soil containers with minimal headspace and no Teflon lid-liners.
Spoil management	Cuttings from boreholes were placed into a skip bin, waste classified and disposed off-site to an appropriately licensed landfill.
Borehole coordinates	All soil borehole locations (that were not converted to monitoring wells) were recorded by a handheld GPS using Map Grid of Australia (MGA94) datum.

3.2.2 Groundwater

Table 16 Groundwater Investigation Methodologies

Activity	Details
Monitoring well installation	<p>Monitoring wells were constructed from machine threaded 50 mm inside diameter well casing made of Class 18 uPVC. In all wells, 3 m long screens with 0.5 mm slotting were used with the exception of MW81 where, 0.5 mm slotted 1.5 m long pre-pack screen was used due to stability issues. The pre-packed screen contained a graded silica sand filter pack encased with a fine stainless steel mesh (0.28 mm pore size).</p> <p>All well installations were completed using a Geoprobe with hollow stem augers or Sonic rig equipped with sonic drill rods and casing.</p> <p>The well casing was inserted inside the drilling rods with 2 mm filter pack sand and bentonite added as the rods were withdrawn. The filter sand was added from the bottom of the hole to approximately 0.5 m above the top of the screened interval followed by a minimum of 0.5 m thickness of hydrated bentonite pellets in shallow wells or 1 to 2 m thickness of bentonite pellets in deep wells. Monitoring wells were finished with flush fitting 'gatic' lids or with steel monument covers.</p> <p>Well construction details are provided in borehole logs provided in Appendix E. Existing well locations were relabelled, the former well ID's and current well ID's are presented in Table T12 in Appendix B</p>
Well development	<p>All new wells were developed using a decontaminated submersible pump to promote connectivity with the aquifer. The pump was decontaminated by flushing approximately 5 L of mains water through the submersible pump between each event. New high density polyethylene (HDPE) tubing was used at each location. All wells were purged until groundwater parameter stabilisation was achieved. At locations where low recharge was encountered, the well was purged dry, allowed to recharge and pumped dry again.</p>
Water level gauging	<p>The standing water levels (SWL) in the selected monitoring wells were measured using an electronic water/oil interface meter prior to purging. Two gauging rounds were undertaken in July to August 2017 and November 2017. An additional data gap gauging event was conducted in May 2018. During each gauging event, the measurements were taken in as close succession as possible to minimise potential temporal variation. The gauging data are presented in Table T2 in Appendix B.</p>
Well purging and geochemical parameters	<p>Following development, the wells were allowed to stabilise for a minimum of seven days. Monitoring wells were then purged using low flow sampling equipment with new HDPE tubing at each location. Geochemical parameters (e.g. temperature, electrical conductivity, redox, dissolved oxygen and pH) were measured by a calibrated water quality meter (WQM) through a flow cell and the SWLs were measured with an oil/water interface probe during purging. Purging continued until the geochemical parameters stabilised to within 10% for three successive readings. The stabilised geochemical parameters are provided in Table T3 in Appendix B. Calibration records for the WQM are provided in Appendix G.</p>
Purge water management	<p>Purged groundwater was placed in labelled 1,000 L intermediate bulk containers (IBC) which were stored on-Site for future management.</p>

Activity	Details
Groundwater sampling from monitoring wells	Groundwater samples were collected from the monitoring wells using low flow methodology. Samples were collected into laboratory supplied jars suitable for taking PFAS samples (i.e. had no Teflon lid inserts). The groundwater samples were collected when the geochemical parameters and SWL had stabilised. Samples for dissolved metals were field filtered (0.45 µm) and placed into laboratory provided acid preserved containers. General observations of the water quality were also recorded including colour, turbidity and odours. Sampling sheets are presented in Appendix G .
Groundwater sampling from residential bores	Laboratory provided sample bottles were placed beneath the tap outlet and the tap slowly opened to collect the first flush of water and immediately capped.
Slug testing	A 1 m long slug consisting of 32 mm diameter PVC pipe filled with clean sand was rapidly lowered into the water in a monitoring well during the falling head tests, and then rapidly lifted out of the water to conduct the rising head tests. The depth to water was gauged manually before and during the test, and water level loggers were used to record groundwater recovery at 0.5 second intervals.
Survey	The newly installed monitoring wells were surveyed by a registered surveyor to obtain ground surface and top of casing elevations in m AHD and in eastings and northings (MGA94 - Zone 56). The survey results are provided on the borelogs in Appendix E .

3.2.3 Surface Water

Table 17 Surface Water Investigation Methodologies

Activity	Details
Surface water sample collection	Samples were collected using a sample pole to retrieve water from the approximate midpoint of the water column. At each location a new laboratory prepared sample bottle was fitted to the sample pole to collect samples. Surface water was then decanted into specific laboratory prepared bottles.
Surface water, Hawkesbury River	All samples were accessed by boat. At each location, samples were collected midpoint of the water column using a new laboratory supplied 125 mL container attached to a telescopic sampling pole and lowered into the surface water to collect a sample from the approximate mid point of the water column.
Geochemical parameters	A calibrated WQM was used to measure geochemical parameters by lowering the probes into the surface water and recording the equilibrated readings. General observations of the surface water quality and flow were recorded (refer to T4 in Appendix B).

3.2.4 Sediment Sampling

Table 18 Sediment Investigation Methodologies

Activity	Details
Drain/Creek/River sediment	Samples were collected by either a Petite Ponar (Hawkesbury River) or hand trowel. The samples were removed from the sampler by gloved hand and placed into laboratory-prepared 250 mL plastic sample containers.
Terrestrial sediment (land aquatic)	Sediment samples were co-located with the surface water samples. Samples were collected from the liner by gloved hand and placed into laboratory-prepared 250 mL plastic sample containers.
Sample logging	Sample logging was in general accordance with the USCS.

3.2.5 Sample Quality Control

Table 19 Sample Quality Control

Activity	Details
Sample storage	The samples were immediately placed into insulated containers with crushed ice and transported to the laboratory under chain of custody documentation.
Decontamination	<p>To minimise the potential for field cross-contamination, a new pair of disposable gloves were used to collect each sample.</p> <p>Soil boreholes: Hollow stem augers were pressure washed with mains water using or brushed and rinsed with water poured from buckets between each drill location. The hand auger was rinsed in a two stage procedure ('dirty' then 'clean' bucket of mains water) between each soil sampling location.</p> <p>Groundwater (low flow sampling): The interface probe was decontaminated in a solution of laboratory supplied deionised water and PFAS free detergent (Liquinox®) followed by a second rinse with deionised water. New sampling tubing was used at each well to reduce the risk of cross contamination.</p> <p>Surface water: Decontamination of the sampling pole was undertaken using a double rinse with laboratory supplied deionised water.</p> <p>Sediment samples: Decontamination of the samplers was undertaken using a double rinse with laboratory supplied deionised water.</p> <p>Equipment rinsate blank samples were obtained by pouring laboratory prepared deionised water over the decontaminated equipment and collecting the rinse into sample containers.</p>
Field QA/QC sample frequency	Field QA/QC samples included intra-laboratory duplicate and inter-laboratory duplicate samples (i.e. splits) and rinsate samples. Duplicate samples were collected at a minimum frequency of 1 in 20 primary samples. Rinsate samples were collected at a rate of one sample per fieldwork day by pouring laboratory supplied deionised water over the decontaminated sampling equipment.

3.3 Laboratory Analysis

The analytical laboratories included:

- ALS Environmental (ALS) of Smithfield, NSW: used as the primary laboratory for soil, groundwater and surface water analyses. ALS utilised methods certified by NATA.
- Envirolab of Chatswood, NSW: used as the secondary laboratory for soil, groundwater and surface water analyses and utilised methods certified by NATA.

Matrices were analysed for the following PFAS suites:

- All soil, groundwater, surface water and sediment samples were analysed for the extended PFAS suite (28 compounds as defined in **Table 1**).

Selected samples were also analysed for:

- Soil: Non-PFAS suite (BTEXN, TRH, eight metals, OCP, OPP, VOC, PAHs and 1,4 dioxane), non contaminant suite [TOC, CEC, total iron and particle size distribution (PSD)].
- Groundwater: Non-PFAS suite (BTEXN, TRH, eight metals, OCP, OPP, VOC, Phenols and PAH), non contaminant suite (aluminium, iron, manganese, pH, total dissolved solids, major cations and anions, and nutrients).
- Surface water: non contaminant suite (pH, total dissolved solids, phosphate, ammonia, nitrate and nitrite).

Laboratory reports and COC documentation are presented in **Appendix I**.

3.4 Quality Assurance and Quality Control

The QA/QC program implemented for the investigation was completed in accordance with the seven-step DQO process, as described in **Section 1.6**. The achievement of the project DQO was demonstrated by reference to the DQIs.

The data validation procedure employed in the assessment of the field and laboratory QA/QC data indicated that the reported analytical results are representative of the sample locations and that the overall quality of the analytical data produced is acceptably reliable for the purpose of the DSI.

3.5 Assessment Criteria

3.5.1 Overview

The CoPC investigated can be broadly split into two groups: PFAS and non-PFAS. PFAS was analysed in all media and non-PFAS analytes were analysed in selected soil, groundwater and surface water samples.

Identifying and selecting appropriate scientifically robust assessment criteria for a site can be a detailed process. Selection and use of assessment criteria were considered in the context of the CSM to ensure appropriate evaluation of potential human health and ecosystem risks.

The adopted PFAS assessment criteria are intended to be conservative, for the initial assessment of human health and ecological risk (i.e. Tier 1).

The assessment criteria in **Table 20** below are sourced from the Defence Contamination Directive (DCD) #8 (Amendment 2, May 2017). This document was published by Defence to provide an interim benchmark to support the progression of relevant activities on the Defence estate in a nationally consistent manner.

In the absence of formal Australian human health or ecological assessment criteria for these emerging contaminants, the DCD8 (Amendment 2) values were adopted from NSW Health (February 2017) – *Final Health Based Guidelines Values (HBGV) for PFAS for use in site investigations in Australia*, developed by Food Standards Australia New Zealand (FSANZ) and the current enHealth Statement: *Interim national guideline on human health reference values for per- and poly fluoro – alkyl substances for use in site investigations in Australia – June 2016*.

3.5.2 PFAS Assessment Criteria

At the time of commencing this report, there were two nationally adopted guidance documents on the assessment of potential health effects from PFAS:

- Department of Health, 2017. Health Based Guidance Values for PFAS for use in site investigations in Australia. April 2017 (DoH, 2017)
- FSANZ, 2017. Perfluorinated chemicals in food. Food Standards Australia New Zealand and associated supporting documents.

During the preparation of this document, the PFAS National Environmental Management Plan (NEMP), January 2018 was released. The NEMP was released by the Heads of EPAs Australia and New Zealand (HEPA) in collaboration with the Australian Government Department of the Environment and Energy (DoEE) to “*achieve a clear, effective coherent and nationally consistent approach to the environmental regulation of PFAS*”. This document is hereafter referred to as the PFAS NEMP (2018) and presents a number of environmental guideline values including guideline values for:

- Drinking water – Health based (consistent values with DoH, 2017)
- Recreational water – Health based (consistent values with DoH, 2017)
- Fresh water – aquatic ecosystems
- Soil – Human health screening values
- Soil – Interim values for ecological exposure

The NEMP is the source document for the criteria adopted in this report. The use of these criteria is further supported by ‘Defence Contamination Directive (DCD) #8 (Version 2) - Screening Guidelines’ dated March 2018 (Department of Defence, 2018).

A summary of the PFAS criteria considered in this report is presented in **Table 20**

Table 20 PFAS criteria summary: human health

Media	Pathway	Chemical	Criteria	Comment/Reference
Human Receptors				
Water	Drinking water – groundwater	PFOS + PFHxS	0.07 µg/L	<p>The values presented in the PFAS NEMP, 2018 are from DoH 2017, which published final health based guidance values for PFAS for use in site investigations in Australia. DoH utilised the TDI for PFOS and PFOA from FSANZ, 2017 and the methodology described in Chapter 6.3.3 of the National Health and Medical Research Council’s (NHMRC) Australian Drinking Water Guidelines (ADWG), 2016 to determine drinking water values.</p> <p>For PFHxS, DoH 2017 noted that ‘<i>FSANZ concluded that there was not enough toxicological and epidemiological information to justify establishing a tolerable daily intake. However, as a precaution, and for the purposes of site investigations, the PFOS tolerable daily intake should apply to PFHxS. In practice, this means that the level of PFHxS exposure should be added to the level of PFOS exposure; and this combined level be compared to the tolerable daily intake for PFOS.</i></p> <p>The values are also presented in DCD8 (March 2018). <i>All groundwater results were compared to these criteria.</i></p>
		PFOA	0.56 µg/L	

Media	Pathway	Chemical	Criteria	Comment/Reference
	Recreational water – surface water	PFOS + PFHxS	0.7 µg/L	The values presented in the PFAS National Environmental Management Plan (NEMP), 2018 are from DoH 2017, which published final health based guidance values for PFAS for use in site investigations in Australia.
		PFOA	5.6 µg/L	As with the drinking water values, the DoH utilised the TDI for PFOS and PFOA from FSANZ, 2017 and 'the methodology described in Chapter 6.3.3 of the NHMRC of the ADWG, 2016 to determine recreational water quality values' (DoH 2017). AECOM notes that Chapter 6.3.3 specifically refers to the calculation of a drinking water value. It is assumed that DoH 2017, applied the approach presented in Chapter 9.3 of NHMRC 2008 and considered a concentration 10 times that of the drinking water criterion for each compound. The values are also presented in DCD8 (March 2018). <i>All surface water results were compared to these criteria.</i>
Soil	Residential with garden/ accessible soil	PFOS + PFHxS	0.009 mg/kg	The values presented in the PFAS National Environmental Management Plan (NEMP), 2018 are based on 20% of FSANZ TDI, i.e. up to 80% of exposure is assumed to come from other pathways. National Environment Protection (Assessment of Site Contamination) Measure Health Investigation Level -A assumptions with home-grown produce providing up to 10% of fruit and vegetable intake (no poultry), also includes children's day care centres, preschools and primary schools. Does not include home-grown poultry/egg.
		PFOA	0.1 mg/kg	

The ANZECC (2000) states “*There is currently no formal and specific international guidance for incorporating bioaccumulation into water quality guidelines. For those chemicals that have the potential to bioaccumulate, the decision scheme provides for site-specific re-assessment of this issue if suitable data become available. Field investigations of residue levels in appropriate organisms may provide additional evidence for whether or not bioaccumulation is an issue at the site under study. In the absence of such local data, a higher level of protection is recommended (e.g. 99% protection for slightly–moderately disturbed systems instead of 95%).*”

The Hawkesbury River, Cooleys Creek and Rickabys Creek are considered to be moderately disturbed systems, therefore the 99% level of protection is appropriate. As this value is below the LOR for PFOS, the LOR of 0.01 µg/L has been adopted as a practical working measure for fresh surface waters and groundwaters discharging to fresh surface waters. A summary of the Ecological PFAS criteria are presented in **Table 21** below.

Table 21 PFAS criteria summary: Ecological

Media	Pathway	Chemical	Criteria	Adopted Value	Comment/Reference
Water	Freshwater	PFOS	0.00023 µg/L	0.01 µg/L	DoEE, 2016 for 99% species protection
		PFOA	19 µg/L	19 µg/L	DoEE, 2016 for 99% species protection
Soil	Residential (Interim soil – ecological indirect exposure)	PFOS	0.01 mg/kg	0.01 mg/kg	The values presented in the PFAS NEMP, 2018 are based on the 2017 Canadian Federal Environmental Quality Guidelines for Residential and Parkland (soil ingestion by a secondary consumer) and Commercial and Industrial – Coarse Soil (concentration in soil that is expected to protect against potential impacts on freshwater life from PFOS originating in soil that may enter the groundwater and subsequently discharge to a surface water body.) Future work is recommended to review these values for the Australian context. The Canadian Guidelines are currently being finalised.
		PFOA	-	-	

The use of screening level ('Tier 1') generic assessment criteria within this report are presented for information and not utilised as a tool for selection of CoPC. The PFAS data within this report are being further considered in the HHRA and ERA (in preparation) and therefore exceedances of specific criterion are not discussed in detail herein.

4.0 Results

4.1 Water Use Survey

As of 05 June 2018, AECOM had received 158 responses to the Water Use Survey from residents who live within, bordering or outside the SA. The Water Use Survey is presented in **Appendix K**.

The Water Use Survey questions were specifically developed to allow for refinement of the water use exposure pathways and considered aspects of bore water uses such as drinking, cooking, showering, washing, irrigation of crops and livestock consumption.

It is noted that of the 157 respondents, only two respondents indicated they use bore water at their properties, only one respondent was within the SA. A copy of the Water Use Survey and a summary of the responses is provided in **Table 22** below.

Table 22 Summary of responses to the Water Use Survey based on 158 surveys returned to date

Scenario	Number Of Responses	Percentage of Respondents (%)
Best description of property/land use*		
Private residential	113	72
Private residential, including fruit or vegetable garden	34	22
Private residential, including chickens/ poultry/ eggs	10	6
Hobby farm, including livestock	2	1
Hobby farm, including chickens/poultry and eggs	0	0
Hobby farm, including fruit, vegetables or honey	0	0
Hobby farm, aquaculture	0	0
Commercial horticultural farm, including edible produce	4	3
Commercial horticultural farm, including turf or other landscaping plants	6	4
Commercial poultry/ egg farm	0	0
Commercial aquaculture farm	0	0
Commercial livestock/ horse breeding business	5	3
Other industrial/ commercial business	4	3
Education facility	1	1
Child care facility	1	1
Medical facility	2	1
Government facility	0	0
Aged care facility	1	1
Sporting facility	0	0
Church	1	1
Water supply to the property*		
Town water connection, currently in use	149	94
Town water connection, not in use	0	0
Bore Water ⁺	2	1
Rainwater tank/s	27	17

Scenario	Number Of Responses	Percentage of Respondents (%)
River/ creek/ drain/ dam on or near the property	9	6
Other	3	2
Local Waterways used for swimming, boating, fishing or other recreational purposes		
Yes	41	26
No	117	74
Local waterways used for irrigation or stock watering		
Yes	11	7
No	149	94
Flood water collects on property in times of heavy rainfall		
Yes	46	29
No	112	71
Property is frequently inundated by a nearby waterbody during times of heavy rainfall		
Yes	17	11
No	140	89

* Note: where multiple responses to one question have been received all have been included.

† Note: one respondent indicating bore water use is located greater than 10 km from the Site and up hydraulic gradient.

4.2 Rainfall

The rainfall record for the fieldwork period (May 2017 to January 2018) was obtained from the BoM Richmond RAAF station (station number 067105). This information is summarised in **Table 23** and provided in **Appendix G**.

The monthly rainfall was below average for all months within the fieldwork period, with the exception of June and October 2017. Rainfall was above average in June 2017 with 122.2 mm recorded (sixth highest on record). Two of the lowest monthly rainfalls were recorded during the fieldwork period, 0.6 mm for July 2017 and 0.2 mm for September 2017, which was significantly below average.

The 68.6 mm recorded on 8 June 2017 was considered the highest daily rainfall observed during the fieldworks program.

Table 23 Rainfall conditions during fieldwork

Month	Monthly Rainfall Total (mm)	Average Monthly Rainfall (mm)	Highest Daily Rainfall Total (mm)
May 2017	15.4	46.1	10.6 (20 May 2017)
June 2017	122.2	57.2	68.6 (8 June 2017)
July 2017	0.6	28.4	0.4 (4 July 2017)
August 2017	16.8	33.1	9.6 (4 August 2017)
September 2017	0.2	44.2	0.2 (14 September 2017)
October 2017	49.8	47.5	33 (12 April 2017)
November 2017	19.4	77.0	7.4 (27 November 2017)
December 2017	46.6	69.7	14.4 (3 December 2017)
January 2017	19.2	84.4	14.8 (9 January 2018)

Notes: Average monthly rainfall derived from data from 1994 to 2018.

4.3 Subsurface Conditions

Subsurface conditions observed during the installation of 25 monitoring wells and 4 soil bores are provided in the borelogs presented in **Appendix E** and summarised in **Table 24** below.

Representative photographs are provided in **Appendix H**, an overview of geological sections and geological cross sections are provided in **Figures 7 to 10** in **Appendix A**.

Across the SA, groundwater strike was observed during drilling at depths ranging from 2.5 m bgs at Rickabys Drop Zone (MW96) to 20.7m bgs near Clarendon Street (MW80). On the lower flood plain terrace, groundwater was encountered at 3 -10 m bgs (MW81 – MW99), while on the elevated terrace containing much of the Site groundwater was observed from 15.1 (MW76) to 20.7mbgs (MW80).

The observed geology was generally consistent with the regional geology presented in **Figure 4**:

- On the lowland floodplain to the North west and North east of the Site, silt, clay and sand was observed, which is consistent with the Lowlands Formation- Qpl
- On the elevated terrace, predominantly fine grained (clay, silt, clayey sands and fine sand) was observed and is generally consistent with the Clarendon Formation - Qpd .

Table 24 Summary of subsurface conditions

Lithology	Description
Fill	Fill material was encountered in many borehole locations across the SA. The maximum fill thickness was 1.8m (MW86), but was typically <0.7m thick. The fill was generally comprised of gravelly sand and gravelly silt with angular to sub-angular igneous road base being the most common gravel clast observed.
Lowlands Formation (Clay, silty clay and sand)	<p>Boreholes located on the broad lower terrace north of the Site typically intersected interbedded clays and silts followed by very fine to fine sands before the borehole termination depth (ranging from 6-12 m bgs). A total of 17 monitoring wells and 4 soil bores intersected this unit.</p> <p><i>Interbedded clay and silts:</i> The finer sediments consisted of clays, clayey silts and silts that were brown to grey with gradational contacts and consistency ranging from soft to firm. The typical thickness for the fine sediments was 3 - 5 m from near surface to approximately 3 - 5 m bgs (Plates 1.1 – 1.4 in Appendix H). Bore hole locations MW85, MW87, MW91 along Cornwallis Rd consisted of clays and silts to greater depths (up to 7.1 m bgs) than other bore holes intersecting the Lowlands Formation.</p> <p><i>Sand and silty sand:</i> Below the fine grained sediments, yellow to brown sand and</p>

Lithology	Description
	<p>silty sand was observed at many locations (i.e.MW81, MW84, MW88). The sands were typically very fine to medium grained, poorly graded, unconsolidated and often saturated (Plates 1.1 – 1.4 in Appendix H). The sands typically contained minor amounts of fine material (< 20% silt and clay). The depth from ground surface to the top of the sands was observed to be 3 - 5 m bgs. To the North west of the Site along Bensons lane the sand unit was observed at shallower depths with the top of the unit at 1.5 - 3 m bgs. The thickness of the sand unit was not obtained as bores were terminated once a sufficient saturated portion of the sand unit was encountered. Particle size distributions for four samples from sands within the well screen interval confirm the field interpreted average particle size and the minor silt and clay content.</p> <p>Borehole location MW92 located adjacent to Rickabys Creek was the only location observed to intersect a full sequence of clays, sands and gravels overlying a basement of shale (Plate 1.5). Unconsolidated sandy gravels consisting of medium gravel to cobble sized clasts were observed from 13.4mbgs to 22.2mbgs. These gravels overlie an indurated basement of shale (Wianamatta Group). Minor peat layers were also observed within the gravels at this location (Plate 1.6).</p>
<p>Clarendon Formation (upper clays and silts, lower fine sands)</p>	<p>Clays and clayey sands underlain by fine sands were intersected in six boreholes located on the elevated terrace where the Site is positioned (MW75, MW76, MW77, MW78, MW79, MW80).</p> <p><i>Clays and silts (upper unit):</i> In all six locations, a predominantly clay and silt unit was observed from surface to maximum depth ranging from 12.0 m bgs (MW75) to 20.7 m bgs (MW80) (Plates 1.7 - 1.9 in Appendix H). The clays and clayey silts were generally orange to grey with occasional mottling and a moderate to high plasticity. The consistency was usually firm to very stiff with occasional iron staining. Minor silt and clayey sand units of up to 1 – 2 m in thickness were observed within the clay unit (i.e.MW80 and MW75). This unit was typically dry to moist but minor saturated zones were observed in the clayey sand (i.e. MW80).</p> <p><i>Fine Sands (lower unit):</i> Underlying the clay unit, a clayey-silty sand or fine sand unit was consistently intersected. This sand unit was typically grey to brown, poorly graded, very fine to fine grained sand with up to 15% clay or silt observed (Plates 1.10 – 1.12 in Appendix H). The sands appeared to fine up with less silt or clay observed at greater depths. A minimum observed thickness of 3.3 m was seen in MW80, but the lower unit is likely to be thicker as the base of the sand unit was not intersected in any of the boreholes. This sand unit was saturated in each bore and was subsequently selected for monitoring well installations. Particle size distributions for two samples from sands within the well screen interval confirm the field interpreted average particle size.</p>
<p>Londonderry Clay (High plasticity, iron stained clays)</p>	<p>A single bore hole (MW94) located to the east of the Site was observed to intersect iron stained moderate to high plasticity clay (Plate 1.13 in Appendix H). The clay was heavily iron stained in some intervals, and contained little moisture to the base of the unit at 12.2 m bgs. The base of the unit had a sharp contact with the underlying gravelly clay (Rickabys Gravel). The Londonderry Clay is mapped in surface geology where MW94 is located (refer to Figure 4 in Appendix H).</p>
<p>Rickabys Creek Gravel (Clayey Gravel)</p>	<p>Gravelly clay was observed from 12.2 -15.4 m bgs in MW94 approximately 1km east of the Site near Moses Street (Plate 1.14 in Appendix H). Clast sizes ranged from fine gravel to cobbles up to 150mm in diameter. The high clay content of the gravel is consistent with the Rickabys Gravel (Jones & Clark 1991).</p>
<p>Wianamatta Group (Shale)</p>	<p>Shale interpreted as the Wianamatta Group was encountered in MW92 near Rickabys Creek at 22.2 m bgs and in MW94 near Moses Street at 15.4 m bgs (Plates 1.15 - 1.17 in Appendix H). The shale was observed to have fine light grey and dark grey laminations and was moderately weathered. Compared to the</p>

Lithology	Description
	overlying sediments this shale was notably more indurated.

PSD analyses were completed on 7 soil samples considered representative of the geological materials encountered during the DSI investigation (**Table T1** in **Appendix B**).

4.4 Hydrogeology

4.4.1 Groundwater Bore Search

A groundwater bore search of the SA was completed, a total of 18 registered bores were identified. In Summary:

- 13 groundwater bores located north west of the Site are identified as irrigation bores and construction depths range from 4.8 m bgs to 16.9 m bgs
- 1 groundwater bore located north west of the Site is identified as a recreational bore and has a constructed depth of 11.5 m bgs
- 1 groundwater bore located north west of the Site is identified as a stock watering bore and has a constructed depth of 16 m bgs
- 1 groundwater bore located south west of the Site is identified as having intended purpose as stock and domestic and has a constructed depth of 84 m bgs
- 2 groundwater bores located west of the Site are identified as stock and domestic and domestic bored and construction depths of 18.30 and 15.0 m bgs.

Information obtained from the NSW Office of Water is provided in **Figure 29** in **Appendix A**.

4.4.2 Groundwater Elevation

The SWL depth was measured in selected wells during groundwater sampling from 3-10 July 2017 (60 monitoring wells), a targeted gauging event on 27 November 2017 (45 monitoring wells), and a data gap gauging event on 14 and 15 May 2018. A summary of depth to groundwater measurements are presented in **Table 25** below, with full results presented in **Table T2** in **Appendix B**.

The measured SWLs and the top of casing elevation data for the November 2017 and May 2018 gauging events were utilised to calculate groundwater elevation in m AHD and generate inferred potentiometric contours for the selected monitoring wells presented in **Figure 11** and **Figure 11B** in **Appendix A**. Hydrographs have been included in **Appendix D**.

Table 25 Summary of groundwater elevations

Event Date	No. Wells	Min SWL (m btoc)	Max SWL (m btoc)	Min GWE (m AHD)	Max GWE (m AHD)
July 2017	60	0.540 (MW12)	16.041 (MW57)	2.260 (MW33)	15.670 (MW71)
November 2017	45	0.698 (MW23)	16.340 (MW58)	-0.272 (MW93)	10.126 (MW94)
May 2018	81	2.99 (MW06)	22.00 (MW77)	-0.593 (MW93)	15.046 (MW71)

Note: GWE – Groundwater Elevation

4.4.3 Groundwater Flow Direction

Based on the SWL and the survey data, the interpreted potentiometric contours are presented in **Figure 11** and **Figure 11B** in **Appendix A**. The data indicate that:

- Groundwater at and down hydraulic gradient of the Site flows to the north east towards the Hawkesbury River

- Groundwater adjacent the north western boundary of the site flows in a north westerly direction towards the unnamed drain.

The groundwater flow regime is discussed further in **Section 5.3**.

4.4.4 Groundwater Geochemical Parameters

The groundwater geochemical parameters measured in the field are presented in **Table T3** in **Appendix B** and summarised in **Table 26** below. The groundwater sampling locations are shown in **Figures 16** to **18** in **Appendix A**. Analytical results are presented in **Section 4.9**. The stabilised geochemical parameter measurements were:

- pH: measurements were between 3.74 (MW56) and 7.35 (MW16) indicating acidic to neutral groundwater conditions
- EC: measurements ranged between 17.7 $\mu\text{S}/\text{cm}$ (MW15) and 11,323 $\mu\text{S}/\text{cm}$ (MW62) indicating fresh to saline groundwater conditions. High EC values (i.e. > 5000 $\mu\text{S}/\text{cm}$) were associated with the Clarendon Formation on the Base (MW09, MW53, MW62 and MW67)
- Dissolved oxygen: measurements ranged between 0.01 mg/L (MW92) and 6.04 mg/L (MW71) indicating that groundwater ranges from anaerobic to well oxygenated conditions
- Temperature: measurements ranged between 13.6 °C (MW04) and 22.6 °C (MW86). Temperature readings varied significantly due to the seasonal ambient temperature differences between July and November experienced at Richmond (refer to **Section 2.3.2** for climate information)
- Redox: measurements ranged between 63 mV (MW78) and 512.5 mV (MW26).

Table 26 Summary of surface water geochemical parameters

Parameter	Minimum (Sample Location)	Maximum (Sample Location)
pH	3.74 (MW56)	7.35 (MW16)
EC ($\mu\text{S}/\text{cm}$)	17.7 (MW15)	11,323 (MW62)
Dissolved Oxygen (mg/L)	0.01 (MW92)	6.04 (MW71)
Temperature (°C)	13.6 (MW04)	22.6 (MW86)
Redox (ORP) (mV)	63 (MW78)	512.5 (MW26)

4.4.5 Hydraulic Conductivity based on Particle Size Distribution

The PSD results for 7 soil samples were used to estimate the hydraulic conductivity of the lithological units.

A relationship between laboratory measured PSD and hydraulic conductivity based on approximately 1,300 samples have been programmed in the Rosetta Model (Zhang and Schaap, 2017). The pedotransfer function was used to estimate the hydraulic conductivity of samples collected from the SA. The lower 10th percentile (d10) was assessed in grain size distribution curves for each sample and was found to be less than 0.1 mm except for the sample from MW92. The Hazen method requires a d10 of 0.1 to 3.0mm to estimate hydraulic conductivity in sandy sediments (Fetter, 2001).

The results of the analyses are presented in **Table 30** below.

Table 27 Hydraulic Conductivity Estimates from Particle Size Distributions

Sample Summary			Pedotransfer Function				Hazen method	
Inferred Formation	Location	Depth Range (m)	Clay (%)	Silt (%)	Sand (%)	K (m/day)	D ₁₀ (mm)	K (m/day)
Clarendon Fm	MW76	16.5 - 16.6	8	16	76	0.65	<1	Cannot estimate K due to D ₁₀ less

Sample Summary			Pedotransfer Function				Hazen method	
Inferred Formation	Location	Depth Range (m)	Clay (%)	Silt (%)	Sand (%)	K (m/day)	D ₁₀ (mm)	K (m/day)
	MW80	22.5 - 22.6	10	5	85	1.18	<1	than 1mm
Lowlands Fm	MW85	7.3 -7.4	13	20	67	0.35	<1	
	MW86	1.5 -1.6	39	55	6	0.12	<1	
	MW98	8.4 - 8.5	12	11	77	0.55	<1	
	MW86	5.8 - 5.9	6	10	82	1.12	<1	
	MW92	20.5 - 20.6	1	0	99 ^a	12.6	0.28	67.74

^a Gravel content has been combined into the sand value for MW92 (50% sand and 49 % gravel)

4.4.6 Hydraulic Conductivity based on Slug Testing

Slug testing was completed on 27 November 2017 at 8 selected monitoring well locations. Tests were conducted following the methods outlined in **Section 3.2.2**. Analyses of the slug test results were completed using Aqtesolv®, Version 4.5 – professional proprietary software from HydroSOLVE Inc. The data were analysed using the Bouwer and Rice method of analysis (Bouwer and Rice, 1976) and Hvorslev method of analysis (Hvorslev, 1951) to calculate aquifer hydraulic conductivity (K). Software outputs and test results are provided in **Appendix G** and summarised in **Table 28** below.

The two locations from the Clarendon Formation indicate this formation has a higher horizontal conductivity than the Lowlands Formation (i.e. groundwater appears to move more quickly in a horizontal direction in the CFA than the LFA). Clarendon Formation test results were typically greater than 2.0 m/day. Within the Lowlands Formation, estimated aquifer hydraulic conductivity values were generally low and associated with silty or clayey sands (< 0.1 m/day). The highest value within the Lowland Formation was associated with the sandy gravel zone near Rickabys Creek (MW93 – 3.35 m/day). Data from MW88 on Cornwallis Road were considered unreliable due to poor rising and falling head response curves.

Table 28 Summary of hydraulic conductivity based on slug tests

Formation	Well ID	Well Screen Lithology	Aquifer Type	Analysis Method ¹	Falling Head	Rising Head	Average K (m/day)
Clarendon Fm	MW76	Very Fine - Fine Sand	Semi-Confined	Hvorslev	Inconclusive	3.408	2.574
				Bouwer and Rice	Inconclusive	1.739	
	MW80	Fine - Medium Sand	Semi-Confined	Hvorslev	5.146	5.782	4.788
				Bouwer and Rice	3.877	4.346	
Lowlands Fm	MW81	Silty Sand	Semi-Confined	Hvorslev	0.024	No Data ^a	0.019
				Bouwer and Rice	0.014	No Data ^a	
	MW85	Clayey Silt	Unconfined	Hvorslev	0.048	0.060	0.049
				Bouwer and Rice	0.034	0.053	

Formation	Well ID	Well Screen Lithology	Aquifer Type	Analysis Method ¹	Falling Head	Rising Head	Average K (m/day)
	MW86	Clayey Sand	Unconfined	Hvorslev	0.051	0.092	0.061
				Bouwer and Rice	0.033	0.068	
	MW88 ^b	Very fine Sand	Unconfined	Hvorslev	4.32	7.56	Inconclusive
				Bouwer and Rice	3.14	5.59	
	MW92	Sandy Gravel	Semi-Confined	Hvorslev	3.882	3.420	3.350
				Bouwer and Rice	3.228	2.870	
	MW98	Clayey Silt and fine Sand	Semi-Confined	Hvorslev	2.004	3.203	2.129
				Bouwer and Rice	1.344	1.965	

Notes: ¹References: Bouwer and Rice (1976); Hvorslev (1951).

^a Insufficient time to complete rising test (slug out)

^b Testing result is considered uncertain and the value is not used to calculate the average hydraulic conductivity

4.5 Surface Water

4.5.1 Surface Water Conditions

The surface water swale drains and opened drains on Base were well defined, appeared unlined and were characterised by low to flat gradients. Water bodies were present on-Site, and consisted of a series of constructed wetlands and settlement ponds on Rickabys Drop Zone. Off-Site surface water drains and creeks were well defined with generally a very low to flat gradient. Bakers Lagoon and Pughs Lagoon, north and west of the Site respectively, were sampled. The on-Site and off-Site drains and surface water bodies observed during the investigation are summarised in **Table 29** below, with photographs of surface water sample locations presented in **Appendix H** (refer to **Plates 2.1 to 2.37**). The surface water locations discussed below are shown in **Figures 19 to 21** (refer to **Appendix A**).

Table 29 Summary of surface water observations

Location	Area	Observations
On-Site	North west of Site (Catchment D)	<p><u>General:</u> Catchment D covers a large area to the north west of the Site and is predominantly grass covered. The Former Fire Training Ground and the Airfield Foam Cannon Testing Area, identified PFAS source zones, are situated in this catchment. The open swale drains and underground stormwater network capture surface water runoff and flow generally in a northerly direction and combine to flow under Dight Street. Surface water is then channelled into a single interceptor pit and open drain directly to the west of the Sewage Treatment Plant (STP) settlement ponds before discharging off-Site at the northern boundary.</p> <p>During the EWP and DSI sampling periods, the swale drains in Catchment D were observed to be dry with the exception of location SW001 on 3 July 2017 where a 10 m section of the drain was observed to be receiving surface water runoff from the Airfield Foam Cannon Testing Area. The open swale drain at this location was grass covered, closely mown and maintained. The bankfull width was 5 m and depth was 0.5 m. Water was colourless, clear with white foam observed to be collecting on the surface. Water depth was 0.1 m at the sample point with no observed flow direction.</p> <p>On 4 July 2017, the drain to the west of the STP settlement ponds was accessed for sample SW002 immediately downstream of the single interceptor pit. The drain was densely vegetated with reeds, grasses and aquatic weeds. The bankfull width was 8 m and depth was 1 m. Water was slightly brown, clear with white foam observed to be collecting on the surface. Water depth was 0.4 m at the sample point with slow flow north towards the Site boundary.</p> <p>Further downstream, location SW003 was sampled on 4 July 2017 at the Site boundary before the drain discharges off-Site. The drain was densely vegetated with reeds, grasses and aquatic weeds. The bankfull width was 10 m and depth was 1 m. Water was colourless, clear with a depth of 0.5 m at the sample point. Water was observed to be flowing slowly off-Site through four 675 mm diameter culverts.</p>
	North western Rickabys Drop Zone (Catchment G)	<p><u>General:</u> Catchment G covers the north eastern area of the Site and contains residences, grassed areas and the hospital on the eastern side of Percival Road. Surface water is captured via an underground stormwater drainage network, and transferred into a series of wetland ponds before discharging off-Site at the northern boundary of Rickabys Drop Zone.</p> <p>On 3 July 2017, location SW014 was sampled at the outlet of the first wetland pond. The wetland was heavily vegetated with reeds and aquatic grasses, with approximate dimensions of 30 m in width and 100 m in length. Water was slightly brown, slightly turbid with organic odour and was 1 m in depth at the sample point. The pond was at capacity and flowing in a southerly direction into a second wetland pond before flowing through an open grassed drain in a north eastern direction to the Site boundary.</p>
	Mid Rickabys Drop	<p><u>General:</u> Catchment A is situated on the eastern side of Percival Road and encompasses the Fuel Farm, which has</p>

Location	Area	Observations
	Zone (Catchment A)	<p>been identified as a PFAS source area. On Rickabys Drop Zone a single interceptor captures surface water from the Fuel Farm before it enters a series of wetland ponds.</p> <p>On 3 July 2017, the outlet of the ponds at both locations (SW012 and SW013) were sampled. The wetland ponds were connected by two 900 mm diameter culverts, heavily vegetated with reeds, lilies and aquatic grasses, with approximate dimensions of 50 m in width and 500 m in length. Water was colourless and clear with a depth of 1 m at both locations. Both ponds were at capacity and were flowing south out of the ponds into the Settlement Pond.</p>
	South Rickabys Drop Zone (Catchment C)	<p><u>General:</u> South Rickabys Drop Zone receives surface water from Catchment C, the largest catchment on-Site. Catchment C includes Fire Station Building 291, Hangar 54, Tanker Parking Area and Former Fuel Farm 1 which are identified PFAS source zones. Open swale drains and an underground stormwater drainage network capture surface water which flows in an easterly direction into a triple interceptor pit, before being transferred via a 1200 mm diameter culvert to the Settlement Pond in Rickabys Drop Zone. At the southern end of the Settlement Pond, surface water discharges via a weir into an open drain flowing in an easterly direction before entering a 900 mm diameter culvert and ultimately discharging off-Site into Rickabys Creek.</p> <p>The Settlement Pond was accessed on 4 July 2017 and location SW011 was sampled in the pond at the outlet of the culvert from the triple interceptor pit. The pond was sparsely vegetated with aquatic weeds and grasses, and had dimensions of 70 m in width and 100 m in length. Water was colourless and clear with a water depth of 0.5 m at the sample point. The Settlement Pond was at capacity, with slow flow over the weir at the southern boundary of the pond.</p> <p>On 3 July 2017, location SW010 was sampled in the open drain immediately before the drain enters a 900 mm culvert and discharges off-Site to Rickabys Creek. The drain was heavily vegetated with reeds, grasses and woody weeds. The bankfull width was 6 m and depth was 1.5 m. Water was colourless and clear with a water depth of 0.3 m at the sample point. Water was observed to be slowly flowing into the culvert.</p>
Rickabys Creek	Upper Rickabys Creek	<p><u>General:</u> The headwaters of Rickabys Creek are located to the south of the Site and flow generally in a northern direction under the Hawkesbury Valley Way towards the eastern boundary of Rickabys Drop Zone approximately 3 km upstream of the junction of the creek with the Hawkesbury River.</p> <p>On 13 November 2017 at location SW020, the upper section of Rickabys Creek was clear of vegetation in channel with minor bank erosion noted on both sides of the creek. The bankfull channel dimensions were 25 m in width with a depth greater than 2 m at the sampling point. The creek did not have any observable flow and water was grey/brown with moderate turbidity.</p> <p>Further downstream, location SW019 was sampled on 4 July 2017. This section of the creek was adjacent to Windsor</p>

Location	Area	Observations
		<p>Golf Course and was heavily vegetated on its banks with woody weeds, grasses and vines. The channel was incised with a bankfull width of 20 m and depth was 10 m. Water at the sample point was 0.4 m in depth, brown, moderately turbid and was slowly flowing downstream to the north.</p>
	<p>North Western Tributaries of Rickabys Creek</p>	<p><u>General:</u> A series of unnamed rural drains form a network of tributaries that flow through the Richmond Lowlands and combine at the northern boundary of Rickabys Drop Zone, flowing south east to intersect Rickabys Creek approximately 2 km upstream of its junction with the Hawkesbury River.</p> <p>Pughs Lagoon sits at the headwaters of the Rickabys Creek Tributaries, and is located to the west of residential properties at Richmond and adjacent to rural properties to the west and north. On 16 November 2017, the Lagoon was clear of vegetation with dimensions of 60 m in width and 500 m in length. Water at the sample point was colourless, clear and 0.2 m in depth. The water level was below the lagoon outlet and therefore not directly connected to the rural drain located to the east.</p> <p>Downstream from Pughs Lagoon, location SW036 was sampled on 16 November 2017 at the point where the rural drain crosses under Onus Lane through two 1200 mm diameter culverts. This section of the drain traverses rural properties and is sparsely vegetated on private property, however heavily vegetated with reeds, grasses and aquatic weeds on the road verge. The bankfull width was 10 m and depth was 1.5 m. Water at the sample point was brown, turbid with an organic odour and sheen. Water depth was 0.4 m and was not observed to be flowing.</p> <p>On 13 November 2017, the rural drain at location SW022 was sampled at the point where the drain crosses under Bensons Lane through two 1200 mm diameter culverts. Additionally, two 1200 mm diameter culverts were noted to be entering the drain from the south west. This section of the drain flows through rural properties and had been recently cleared of vegetation on the property downstream to the east and at the road verge. Bankfull width was 8 m and depth was 1.5 m. Water at the sample point was slightly green, slightly turbid and 0.4 m in depth. No flow was observed in the drain.</p> <p>On 13 November 2017, access was obtained to sample location SW034 at the point where the rural drain traverses through private property. At the time of sampling the water was observed to be being extracted from the drain and used for an irrigated crop to the south, directly adjacent to the drain. Vegetation in channel was sparse with limited sections of aquatic weeds and grasses. Bankfull width was 5 m and depth was 2 m. Water was brown, turbid and 2 m in depth at the sample point. No flow was observed in the drain.</p> <p>At the same property as location SW034 discussed above, a dam approximately 250 m to the north of the rural drain was sampled as location SW033 on 13 November 2017. The dam had no direct connection to the rural drain or to Bakers Lagoon (approximately 500 m to the north) and was described by the landowner as being spring fed. There was</p>

Location	Area	Observations
		<p>no vegetation within the dam, which had dimensions of 30 m in width and 70 m in length. Water was brown, turbid with an organic odour and sheen with a depth of 1 m at the sample point.</p> <p>Location SW015 was sampled on 3 July 2017 at the point where a bridge on Cupitts Lane crossed the rural drain. Tidal gate infrastructure was noted on the eastern side of the bridge and appeared to be restricting water movement at the time of sampling. The channel was heavily vegetated with reeds at the sample point. Bankfull width was 10 m and depth was 2 m. Water was colourless, clear, with a very slight organic sheen. Water depth was 0.5 m at the sample point and was not observed to be flowing.</p> <p>Location SW004 was accessed on 4 July 2017, where an additional unnamed drain crosses through the northern section of Rickabys Drop Zone before entering the north western tributary of Rickabys Creek. This section of drain receives water from rural properties to the north of Rickabys Drop Zone as well as surface water discharging off-Site from Catchment G. The channel was heavily vegetated with grasses, vines and woody weeds. Bankfull width was 5 m and depth was 2 m. Water was very slightly brown, slightly turbid with slow flow to the east.</p> <p>On the north eastern side of Rickabys Drop Zone the rural drain was accessed on 4 July 2017 at locations SW005, SW006 and SW007. This section of the drain flows in a south eastern direction adjacent to the boundary of Rickabys Drop Zone before intersecting Rickabys Creek. The drain through this reach was sharply incised with sparse vegetation in the channel, however heavily vegetated with woody weeds on its banks. At locations SW005 and SW006 bankfull width and depth was 20m and 4 m respectively, increasing to a bankfull width of 30 m and depth of 6 m at SW007. Water was slightly brown, slightly turbid with an organic odour and sheen and was not observed to be flowing. Water depth was 1.0 m at the sample locations.</p>
	Lower Rickabys Creek	<p><u>General:</u> The lower reach of Rickabys Creek flows adjacent to the eastern boundary of Rickabys Drop Zone before meandering generally in an easterly direction to its junction with the Hawkesbury River.</p> <p>Sample point SW009 was accessed on 3 July 2017, and is located at the point where surface water originating from the open drain on-Site at sample location SW010 which discharges to Rickabys Creek from a 900 mm diameter culvert. The channel at SW009 was clear of vegetation; however the banks were heavily vegetated with woody weeds. Bankfull width was 20 m and depth was 8 m. Water was brown and turbid with a depth greater than 1.5 m at the sample point. There was no observed flow in the creek, however inflow was observed from the on-Site discharge culvert.</p> <p>At the junction of Rickabys Creek and the northern tributaries, sample location SW008 was accessed on 3 July 2017. The creek was sparsely vegetated with willows; however the banks were incised and heavily vegetated with vines, shrubs and woody weeds. The bankfull width was 60 m and depth was 10 m. Water was brown, turbid with a slight organic sheen. Water depth was greater than 1.5 m at the sample point and no flow was observed.</p>

Location	Area	Observations
		<p>Location SW023 was sampled on the 13 November 2017, and is located at the point where John Pilot Rickerby Bridge on Cornwallis Road crossed Rickabys Creek. The channel at this section was clear of vegetation; however the banks were incised and heavily vegetated with vines, shrubs and woody weeds. Bankfull width was 30 m and depth was 10 m. Water was grey/brown, moderately turbid and 0.3 m in depth at the sample point. Moderate flow was observed to be moving in an easterly direction.</p> <p>At Deerrubin Park, location SW018 was sampled on 4 July 2017 and is located where a bridge connecting Deerrubin Park to Howe Park crosses Rickabys Creek, approximately 50 m before its junction with the Hawkesbury River. Similar to upstream location SW023, SW018 was clear of vegetation in channel and heavily vegetated on its banks with vines, shrubs and woody weeds. Bankfull width was 40 m and depth was 10 m. Water was brown, moderately turbid and 1.0 m in depth at the sample point. No observed flow was noted.</p>
Cooleys Creek		<p><u>General:</u> A number of ephemeral rural drains on the Richmond Lowlands form a network that drain into Bakers Lagoon at the headwaters of Cooleys Creek. At the southern boundary of the lagoon Cooleys Creek flows in an easterly direction towards the Hawkesbury River.</p> <p>The STP on-Site was accessed, and location SW037 was sampled on 27 November 2017. A water sample was collected from a concrete weir at the north eastern end of the settlement pond immediately before treated water discharges to a pipe that flows to Bakers Lagoon. The settlement ponds were lined, and were of dimensions of 120 m in width and 150 m in length. Water was slightly green, slightly turbid, with organic odour and algae present. Slow flow over the weir into the discharge point was noted.</p> <p>On 13 November 2017, location SW032 was sampled where Bakers Lagoon can be accessed through private property. The lagoon is surrounded by rural properties. The lagoon was clear of vegetation with dimensions of 120 m in width and 500 m in length. Water was slightly brown, slightly turbid and deeper than 1 m at the sample point. Based on the grassed vegetation on the banks Bakers Lagoon appeared to be at capacity; however the southern boundary of the lagoon could not be accessed to confirm flow to Cooleys Creek.</p> <p>Location SW016 was sampled on 3 July 2017, and was located where a bridge on Cupitts Lane crossed Cooleys Creek. The channel at this section was heavily vegetated with reeds, vines and woody weeds. Bankfull width was 30 m and depth was 4 m. Water depth was 0.5 m and was slightly brown, slightly turbid, with organic odour and algae present. The water body was not continuous and water was only present in an isolated pool under the bridge.</p> <p>Further downstream, location SW017 was sampled on 3 July 2017 and was located where a bridge on Cornwallis Road crossed Cooleys Creek. The creek was heavily vegetated with vines, shrubs and woody weeds. Bankfull width was 50</p>

Location	Area	Observations
		m and depth was 5 m. Water was brown, turbid and 0.2 m in depth. The water body was not continuous and water was only present in an isolated pool under the bridge.
Hawkesbury River		<p><u>General:</u> The Hawkesbury River is formed at the confluence of the Nepean and Grose Rivers, approximately 7 km to the southwest of the Site. The river flows around the Richmond Lowlands and receives surface water from Cooleys and Rickabys Creek.</p> <p>On 13 November 2017, eight surface water locations (SW024 to SW031) were sampled on the Hawkesbury River between North Richmond and Windsor. The Hawkesbury River was clear of vegetation in channel and was generally heavily vegetated with vines, grasses and woody weeds on its banks. The river was approximately 130 m in width and depth at the sample points varied from 0.5 to 2.5 m. Water was colourless to slightly brown, slightly turbid with no odour. Water flow was evident at all sample locations.</p>

4.5.2 Surface Water Geochemical Parameters

The surface water geochemical parameters measured in the field are presented in **Table T4** in **Appendix B** and summarised in **Table 30** below. The surface water sampling locations are shown in **Figures 19 to 21** in **Appendix A**. Analytical results are presented in **Section 4.10**. The stabilised geochemical parameter measurements were:

- pH: measurements were between 5.78 (SW014) and 9.30 (SW037)
- EC: measurements ranged between 174.1 $\mu\text{S}/\text{cm}$ (SW012) and 1718.0 $\mu\text{S}/\text{cm}$ (SW015)
- Dissolved oxygen: measurements ranged between 0.05 mg/L (SW036) and 7.98 mg/L (SW030), where the DO was with oxygen solubility limits
- Temperature: measurements ranged between 6.9 °C (SW005) and 26.6 °C (SW037). Temperature readings varied significantly due to the seasonal ambient temperature differences between July and November experienced at Richmond (refer to **Section 2.3.2** for climate information)
- Redox: measurements were between 78.3 mV (SW017) and 350.2 mV (SW012).

Table 30 Summary of surface water geochemical parameters

Parameter	Minimum (Sample Location)	Maximum (Sample Location)
pH	5.78 (SW014)	9.30 (SW037)
EC ($\mu\text{S}/\text{cm}$)	174.1 (SW012)	1718.0 (SW015)
Dissolved Oxygen (mg/L)	0.05 (SW036)	8.21 (SW025)
Temperature (°C)	6.9 (SW005)	26.6 (SW037)
Redox (ORP) (mV)	78.3 (SW017)	350.2 (SW012)

Note: ¹The theoretical maximum value of oxygen solubility, considering the water temperature and specific conductance conditions observed in the field is estimated to be 8.03 mg/L (USGS, 2016). Any value measured above this value has been considered to be erroneous.

4.6 Sediment Observations

Sediment conditions observed during the sampling program are summarised in **Table 31** below. Sediment sampling locations are shown in **Figures 22 to 24** in **Appendix A**. Analytical results are presented in **Section 4.11**.

Table 31 Summary of sediment observations

Location	Area	Observation
On-Site	North west of Site (Catchment D)	Sediment in the swale drain on-Site was brown, soft, low plasticity clay with organic content to 10%. Lower in the catchment, sediment was dark grey, very soft, low plasticity silts with organic content to 10%.
	North west Rickabys Drop Zone (Catchment G)	Sediment in the wetland pond was brown, soft, low plasticity silt with fine to medium sand content to 20% and organic content to 20%.
	Mid Rickabys Drop Zone (Catchment A)	In the constructed wetland ponds sediment was brown, soft, low plasticity silt with fine to medium sand content to 20% and organic content to 10%.
	South Rickabys Drop Zone (Catchment C)	Within the settlement pond sediment was dark grey, fine to coarse sand with silt content to 20% and organic content to 20%. In the open drain downstream of the settlement pond, sediment was dark grey, very soft, low plasticity silt with organic content to 30%.

Location	Area	Observation
Rickabys Creek	Upper Rickabys Creek	In the upper catchment sediment was grey, stiff, low plasticity clay with fine sand content to 20%. Downstream, sediment was brown, soft, low plasticity clay with silt content to 30% and organic content to 5%.
	North Western Tributaries of Rickabys Creek	Sediment at Pughs Lagoon was light yellow, soft, low plasticity sandy clay with fine sand content to 30%. Lower in the catchment sediment variably changed between dark brown, very soft, low plasticity silts to dark brown, soft to stiff, high plasticity clays. Organic content varied between 5% and 40%.
	Lower Rickabys Creek	Sediment was dark grey to dark brown, soft, low plasticity silts with variable organic content between 10% and 20%. Towards the junction with the Hawkesbury River, sediment was dark brown, low plasticity clay with silt content to 30% and organic content to 5%.
Cooleys Creek		Within Bakers Lagoon sediment was brown, medium stiff, high plasticity clay with silt content to 10%. Lower in the catchment, sediment varied between brown, soft, low plasticity silt to brown, loose, fine grained, clay sand. Organic content varied between 5% and 40%.
Hawkesbury River		In the upper reach of the Hawkesbury River sediment varied between soft, low plasticity silty clays to brown, medium grained sand with fine gravels grading to cobbles. Inclusion of shell fragments were noted between 5% and 20%. Lower in the river, sediment was brown, fine to medium sand with shell inclusions to 30%.

4.7 Soil Analytical Results: Unsaturated Zone

Unsaturated zone soil samples were obtained during the DSI field program from six locations on-Site and 23 locations off-Site between 31 October 2017 and 16 November 2017. Additionally, three surface soil samples were obtained from a residential property on 16 November 2017.

4.7.1 PFAS in Unsaturated Zone

Unsaturated soil PFAS analytical results are summarised in **Table 32** and **Table 33** below, and are presented in **Table T5 (Appendix B)** and in **Figures 13 to 15 (in Appendix A)**. In summary:

- PFOS concentrations were above the LOR in 24 samples, with the maximum concentration (0.58 mg/kg) reported in on-Site sample location QC184 (duplicate of BH03_0.1 located within the STP)
- PFOA concentrations were above the LOR in 10 samples, with the maximum concentration (0.017 mg/kg) reported in on-Site sample BH03_0.1 located within the STP
- PFOS and PFHxS concentrations were above the LOR in 25 samples, with the maximum concentration (0.82 mg/kg) reported in on-Site sample location QC184 (duplicate of BH03_0.1 located within the STP).

Table 32 Summary of PFAS in unsaturated soil on-Site

No. Samples Analysed	Compound	Concentration Range, mg/kg (location_depth)	No. Samples with Concentrations >LOR
10	PFOS	<LOR – 0.5840 (QC184, duplicate of BH03_0.1)	8
10	PFOA	<LOR – 0.0168 (BH03_0.1)	6
10	PFOS + PFHxS	<LOR – 0.8240 (QC184, duplicate of BH03_0.1)	8

Table 33 Summary of PFAS in unsaturated soil off-Site

No. Samples Analysed	Compound	Concentration Range, mg/kg (location_depth)	No. Samples with Concentrations >LOR
33	PFOS	<LOR – 0.0768 (MW79_0.5)	13
33	PFOA	<LOR – 0.0003 (MW79_0.5)	2
33	PFOS + PFHxS	<LOR – 0.0773 (MW79_0.5)	14

4.7.2 Non-Contaminant Analyses

Results for non-contaminant analyses performed are summarised in **Table 34** below, and are presented in **Table T7** in **Appendix B**.

Table 34 Summary of non-contaminant analyses in unsaturated soil

No. Samples Analysed	Analyte	Concentration Range, (location_depth)
Physical Parameters		
12	Cation Exchange Capacity	0.7 – 15.4 meq/100g (MW93_10.8)
11	Organic Carbon	0.06 – 0.78 % (MW93_10.8)
12	Fe	1,710 – 29,900 mg/kg (BH04_0.5)

4.8 Soil Analytical Results: Saturated Zone

Saturated zone soil samples were obtained during the DSI field program from the approximate mid screen at all 25 new monitoring well locations between 31 October 2017 and 16 November 2017, and initially placed on hold at the laboratory. Subsequently, 7 samples were analysed for PFAS, due to detections of PFAS within the respective monitoring wells.

Saturated soil PFAS analytical results are summarised in **Table 35** below, and are presented in **Table T6 (Appendix B)**.

- PFOS concentrations were above the LOR in one sample, with the maximum concentration (0.0008 mg/kg) reported in off-Site sample location MW80.
- PFOA concentrations were below LOR in all samples
- PFOS and PFHxS concentrations were above the LOR in one sample, with the maximum concentration (0.0019 mg/kg) reported in off-Site sample location MW80.

Table 35 Summary of PFAS in saturated soils

No. Samples Analysed	Compound	Concentration Range, mg/kg (location_depth)	No. Samples with Concentrations >LOR
7	PFOS	<LOR – 0.0008 (MW80_22.5)	1
7	PFOA	Not detected	0
7	PFOS + PFHxS	<LOR – 0.0019 (MW80_22.5)	1

4.9 Groundwater Analytical Results

During the EWP field program, groundwater samples were collected from 65 on-Site locations between 30 June 2017 and 10 July 2017. Following the installation of groundwater monitoring wells

during the DSI, two groundwater wells were sampled on-Site and 24 locations were sampled off-Site. Additionally, two residential bores were sampled between 28 August 2017 and 16 November 2017.

4.9.1 PFAS

Groundwater PFAS analytical results are summarised in **Table 36** to **Table 38** below, and are presented in **Table T8** (in **Appendix B**) and in **Figures 16** to **18** (in **Appendix A**). In summary:

- PFOS concentrations were above the LOR in 61 samples, with the maximum concentration (872 µg/L) reported in on-Site sample location MW40, located adjacent to the Former Fire Training Area
- PFOA concentrations were above the LOR in 40 samples, with the maximum concentration (9.8 µg/L) reported in on-Site sample QC207 (duplicate of MW40)
- PFOS and PFHxS concentrations were above the LOR in 78 samples, with the maximum concentration (969 µg/L) reported in on-Site sample location MW40.

Table 36 Summary of PFAS in groundwater on-Site

No. Samples Analysed	Compound	Concentration Range, µg/L (location)	No. Samples with Concentrations >LOR
75	PFOS	<LOR – 872 (MW40)	54
75	PFOA	<LOR – 9.8 (QC207, duplicate of MW40)	37
75	PFOS + PFHxS	<LOR – 969 (MW40)	67

Table 37 Summary of PFAS in groundwater off-Site

No. Samples Analysed	Compound	Concentration Range, µg/L (location)	No. Samples with Concentrations > LOR
29	PFOS	<LOR – 2.51 (MW80)	7
29	PFOA	<LOR – 0.25 (MW80)	3
29	PFOS + PFHxS	<LOR – 6.31 (MW80)	12

Table 38 Summary of PFAS in groundwater in residential bores

No. Samples Analysed	Compound	Concentration Range, µg/L (location)	No. Samples with Concentrations >LOR
4	PFOS	<LOR – 0.19 (BW002)	2
4	PFOA	Not detected	Nil
4	PFOS + PFHxS	<LOR – 0.23 (BW002)	2

4.9.2 Non-Contaminant Analyses

Results for non-contaminant analyses are summarised in **Table 39** below, and are presented in **Table T9** in **Appendix B**.

Table 39 Summary of non-contaminant analytes in groundwater

Samples Analysed	Analyte	Concentration Range, mg/L (location)
Physical Parameters		
28	pH	5.58 (MW90) – 7.73 (MW86)
Cations/anions		

Samples Analysed	Analyte	Concentration Range, mg/L (location)
96	Calcium	<LOR – 266 (MW05)
96	Magnesium	3 – 458 (MW05)
96	Sodium	10 – 3470 (MW05)
96	Potassium	1 – 10 (MW46)
96	Chloride	13 – 6680 (MW05)
94	Sulphate as SO ₄ ²⁻	1 – 996 (MW05)
95	Total alkalinity as CaCO ₃	30 – 1150 (MW52)
95	TDS	112 – 14,700 (MW05)
Metals		
101	Aluminium	<LOR – 3.19 (MW26)
101	Iron	<LOR – 105 (MW92)
101	Manganese	<LOR – 10.1 (MW97)
Nutrients		
80	Ammonia	<LOR – 6.2 (MW93)
78	Nitrate	<LOR – 106 (MW47)
78	Nitrite	<LOR – 0.25 (MW95)

4.10 Surface Water Analytical Results

Surface water samples were collected during the EWP field program from 14 on-Site and 5 off-Site locations between 3 July 2017 and 4 July 2017. Prior to sampling in July, 122 mm of rainfall was recorded for June on-Site which was significantly higher than the long term average of 57mm (refer to the Monthly Rainfall Figure in **Appendix D**).

During the DSI field program one additional location was sampled on-Site and 18 locations off-Site between 13 November and 27 November 2017. With the exception of October, all monthly rainfall totals were below average between the EWP sampling in July and leading up to the DSI field program in November (Monthly Rainfall Figure in **Appendix D**).

4.10.1 PFAS

Surface water PFAS analytical results are summarised in **Table 40** and **Table 41** below, and are presented in **Table T10** (in **Appendix B**) and in **Figures 19 to 21** (in **Appendix A**). In summary:

- PFOS concentrations were above the LOR in 37 samples, with the maximum concentration (53.5 µg/L) reported in on-Site sample location SW002 (adjacent the STP)
- PFOA concentrations were above the LOR in 26 samples, with the maximum concentration (10.1 µg/L) reported in on-Site sample location SW001 (adjacent to the Airfield Foam Cannon Testing Area)
- PFOS and PFHxS concentrations were above the LOR in 37 samples, with the maximum concentration (83.9 µg/L) reported in on-Site sample location SW002 (adjacent the STP).

Table 40 Summary of PFAS in surface water, on-Site

No. Samples Analysed	Compound	Concentration Range, µg/L (location)	No. Samples with Concentrations >LOR
18	PFOS	0.08 – 53.5 (SW002)	18
18	PFOA	<LOR – 10.1 (SW001)	17

No. Samples Analysed	Compound	Concentration Range, µg/L (location)	No. Samples with Concentrations >LOR
18	PFOS + PFHxS	0.12 – 83.9 (SW002)	18

Table 41 Summary of PFAS in surface water, off-Site

No. Samples Analysed	Compound	Concentration Range, µg/L (location)	No. Samples with Concentrations >LOR
23	PFOS	<LOR – 3.06 (SW032)	19
23	PFOA	<LOR – 0.27 (SW032)	9
23	PFOS + PFHxS	<LOR – 4.75 (SW032)	19

4.10.2 Non-Contaminant Analyses

Results for non-contaminant analyse are summarised in **Table 42** below and are presented in **Table T9** in **Appendix B**.

Table 42 Summary of non-contaminant analytes in surface water

No. Samples Analysed	Analyte	Concentration Range, mg/L (location)
Physical Parameters		
3	pH	7.00 (SW036) – 9.56 (SW037)
Cations/anions		
7	Calcium	6 – 19 (SW009)
7	Magnesium	2 – 28 (SW009)
7	Sodium	7 – 150 (SW009)
7	Potassium	2 - 9 (SW009)
7	Chloride	8 - 306 (SW009)
7	Sulphate as SO ₄ ²⁻	7 – 44 (SW001)
7	Total alkalinity as CaCO ₃	28 - 62 (SW009)
25	TDS	64 – 1,420 (SW033)
Nutrients		
19	Ammonia	<LOR – 0.47 (SW036)
20	Nitrate	<LOR – 0.55 (SW033)
20	Nitrite	<LOR – 0.03 (SW037)
19	Reactive phosphorus	<LOR – 0.63 (SW037)

4.11 Sediment Analytical Results

Sediment samples were collected during the EWP field program from 14 on-Site and 5 off-Site locations between 3 July 2017 and 4 July 2017. During the DSI field program an additional 18 locations off-Site were sampled between 13 November and 16 November 2017.

4.11.1 PFAS

Sediment PFAS analytical results are summarised in **Table 43** and **Table 44** below, and are presented in **Table T11** (in **Appendix B**) and in **Figures 22 to 24** (in **Appendix A**). In summary:

- PFOS concentrations were above the LOR in 31 samples, with the maximum concentration (38.9 mg/kg) reported in on-Site sample location SD001, located adjacent to the Airfield Foam Cannon Testing Area.
- PFOA concentrations were above the LOR in 26 samples, with the maximum concentration (0.63 mg/kg) reported in on-Site sample location SD001
- PFOS and PFHxS concentrations were above the LOR in 31 samples, with the maximum concentration (39.6 mg/kg) reported in on-Site sample location SD001.

Table 43 Summary of PFAS in sediment, on-Site

No. Samples Analysed	Compound	Concentration Range, mg/kg (location)	No. Samples with Concentrations > LOR
17	PFOS	0.007 – 38.9 (SD001)	17
17	PFOA	<LOR – 0.63 (SD001)	14
17	PFOS + PFHxS	0.007 – 39.6 (SD001)	17

Table 44 Summary of PFAS in sediment, off-Site

No. Samples Analysed	Compound	Concentration Range, mg/kg (location)	No. Samples with Concentrations >LOR
23	PFOS	LOR – 0.0532 (SD032)	15
23	PFOA	LOR – 0.0013 (SD18)	3
23	PFOS + PFHxS	LOR – 0.0549 (SD032)	15

4.11.2 Non-Contaminant Analyses

Results for non-contaminant analyses are summarised in **Table 45** below, and are presented in **Table T7** in **Appendix B**.

Table 45 Summary of non-contaminant analytes in sediment

No. Samples Analysed	Analyte	Concentration Range, (location)
Physical Parameters		
18	pH	6.0 – 7.8 (SD034)
18	EC	20 - 252 μ S/cm (SD020)
24	Cation Exchange Capacity	0.3 – 16.9 meq/100g (SD034)
23	Total Organic Carbon	0.09 – 5.49 % (SD022)
24	Fe	2,440 – 53,100 mg/kg (SD023)

4.12 AFFF Concentrate

On 27 November 2017, a sample of AFFF concentrate was obtained from a new, sealed 200 L drum of Ansilite™ (3%) at the Fire Station (Building 291). PFAS analytical results are summarised in **Table 46** below, and are presented in **Table T13** (in **Appendix B**).

Table 46 Summary of PFOS, PFOA and PFOS + PFHxS in AFFF concentrate

No. Samples Analysed	Compound	Concentration ($\mu\text{g/L}$)	No. Samples with Concentrations > LOR
3	PFOS	Not detected	Nil
3	PFOA	400 – 562	3
3	PFOS + PFHxS	Not detected	Nil

5.0 Discussion

5.1 Subsurface Geological Conditions

The observed subsurface lithology was generally consistent with the mapped surface geology displayed in **Figure 4** in **Appendix A**. Subsurface conditions encountered in the DSI are provided on borelogs in **Appendix E**, and geological cross-sections interpreted from drilling observations are presented in **Figures F7 to 10** in **Appendix A**.

5.1.1 Lowlands Formation

The Lowlands Formation was intersected in 17 boreholes located on the lower floodplain terrace, including Rickabys Drop Zone (**Figure 4** in **Appendix A**).

The Lowlands Formation is understood to consist of a basal gravelly unit and a stratigraphically higher sequence of finer sediment including fine sands, silts and clays (Jones and Clark, 1991). This fining up sequence is related to the flood plain of Hawkesbury River. The drilling works to the north and north east of the Site predominantly intersected this upper sequence of finer sediments within the formation. Boreholes were terminated in the first saturated zone encountered - typically fine sand or silty sands beneath dry to moist clays and silts. Exceptions were MW97 on Cupitts Lane, MW91 on Cornwallis Rd and MW93 near Rickabys Creek where the saturated zone was within clay dominated material (**Appendix E**).

No gravels were encountered in any drill holes on the lower floodplain terrace, except at MW92 near Rickabys Creek where the complete Lowlands Formation sequence was intersected (total thickness of ~22m). The thickness of the Lowlands Formation could not be assessed elsewhere due to the shallow depth of drill holes on the floodplain but it is possible that gravels lie at depth beneath many of the drilled locations.

Lateral variations within the Lowlands Formation were observed. For example:

- Clayey and silty fine sands were observed in the saturated zone to the north-west of the Site (i.e. MW81 to MW85.) while in contrast, clean fine sands were observed to the north and north east of the Site (i.e. MW87-MW89 and MW99 and MW98).
- On Cupitts Lane, clayey silt extended to 7.8 m bgs at MW98, while 400m to the south at MW99 sands were encountered much shallower at 3.8mbgs.

This variability is consistent with a flood plain depositional environment where channel and over bank deposits interacted over time.

5.1.2 Clarendon Formation

The Clarendon Formation is inferred to have been intersected in 6 drill holes during the DSI investigation, and defines the elevated terrace above the lower floodplain terrace of the Lowlands Formation.

Based on observations during the DSI investigation, two broad units were identified: an upper unit of fine grained sediments (clays and silts), and a lower unit of fine sands:

5.1.2.1 Upper unit

The upper unit consisted of predominantly firm to stiff clays, clayey silts and silts with low permeability. The thickness of the upper unit varied between 12.1 m (MW75) to 20.7 m (MW80) in thickness and was observed to be predominantly dry to moist, with no saturated zones identified. Minor silt and sand beds were occasionally present with a thickness of up to 1 m (MW80). These were occasionally saturated.

5.1.2.2 Lower unit

Drilling to the west and southwest of the Site demonstrated there is a laterally continuous sand unit beneath the overlying clays and silts. Drilling of Noel Arnold and Associates (2011) also encountered sands and silty sands at comparable depths beneath the clays and silts on the Site [i.e. SW0138-NAA-MW01 (relabelled MW53), SW0061-NAA-MW03 (relabelled MW49) and SW0263-NAA-MW01

(MW36)]. From historical drilling in the region, Jones and Clark (1991) noted that a coarse sand and gravel zone exists beneath the dense clays of the Clarendon Formation.

The lower unit was generally saturated. This unit represents the main aquifer of the Clarendon Formation. Boreholes were terminated once this saturated zone encountered. The total thickness may extend beyond 3 m, as indicated by MW80.

5.1.3 Londonderry Clay

The Londonderry Clay is interpreted to have been intersected in only one bore hole (MW94) to the north east of the Site. It consisted of a brown to dark orange, medium to high plasticity, dry clay and contained no saturated zones.

5.1.4 Rickabys Creek Gravel

The Rickabys Creek Gravel is characterised by a high matrix content of sand and clay and stratigraphically underlies the Londonderry Formation (Jones and Clark, 1991). The Rickabys Creek Gravel was interpreted to have been intersected in one borehole north east of the Site (MW94). Here, the observed material consisted of gravelly clay with approximately 10-20% gravels and trace cobbles beneath clays interpreted as Londonderry Clay (**Appendix E**). The Rickabys Creek Gravel was not intersected in any other boreholes, indicating that the unit may have a limited presence within the SA.

5.1.5 Wianamatta Group

The Wianamatta Group underlies the SA and forms the base of the CFA and LFA. The shale unit was intersected in two boreholes (MW92 and MW94), and consisted of light to dark grey moderately weathered shale.

5.2 PFAS in Soil

Unsaturated zone soil sample results are presented in **Figures 13 to 23 in Appendix A**, and discussed in the following sections. The concentrations of PFAS in soils are described by colours in the figures (**Figures 13 to 23 in Appendix A**).

5.2.1 On-Site

Shallow surface samples were collected on-Site from the STP and Rickabys Drop Zone. The results show that:

- **STP:** Sum of PFOS and PFHxS concentrations reported within the STP ranged from 0.0104 mg/kg (0902_BH02_1.5_161117) to 0.824 mg/kg (0902_QC184_161117, intra laboratory duplicate of 0902_BH03_0.1_161117). Limited soil data have been collected from the STP, however it is considered possible that the soils act as an ongoing secondary source of PFAS contamination.
- **Rickabys Drop Zone:** Sum of PFOS and PFHxS concentrations reported within Rickabys Drop Zone ranged from non-detect (0902_MW96_021117) to 0.006 mg/kg (0902_MW95_0.5_021117). Limited soil data has been collected on Rickabys Drop Zone, however it is considered unlikely that the soils act as an ongoing source of PFAS contamination, due to the relatively low concentrations reported.

Waste classification works performed by Jacobs on in-situ soils associated with upgrade works on the on-Site swale drainage system (Jacobs, 2016). Reported PFOS concentrations were up to 59.4 mg/kg, with leachable concentration of PFOS reported as 3080 µg/L (after toxicity characteristic leaching procedure was performed). Soil excavated from the swale drains during upgrade works is currently stored in temporary stockpiles with plastic lining. Given the drains have been constructed without lining, water can infiltrate freely through the soil profile, deeper soils within the drainage network may act as ongoing secondary sources of PFAS contamination.

5.2.2 Off-Site

A total of 36 shallow soil samples were collected from the upper 1.5 m of the soil profile in which PFOS was detected in 16 samples, results are presented in **Table T5 in Appendix B**. The maximum sum of PFOS and PFHxS concentration was 0.0773 mg/kg from 0.5 m bgs at location MW79. There was an evident trend of PFAS concentration as a function of sampling depth, with samples collected

from between the surface and 0.5 m bgs being more likely to report a detection and greater PFAS concentration (refer to **Table 47**). It is possible that off-Site shallow soil detections may be the result of PFAS infiltration from contaminated surface waters being used for irrigation.

Table 47 Comparison of PFOS + PFHxS with depth

Depth	No. Samples	No. Detects	% of Samples with Detects	Average PFOS + PFHxS Conc. (µg/L)
0.1	11	9	91	0.0036
0.5	8	5	63	0.0169
1.0	10	2	20	0.0002
1.5	7	0	0	NA

Shallow soil samples collected to the north west of the Site boundary (MW79 and MW80) were reported to contain greater PFAS concentrations than samples collected at other off-Site locations. The potential for windblown transport of PFAS is discussed in **Section 5.5.6**.

5.3 Hydrogeology

5.3.1 Thickness and Extent of Aquifers

Groundwater beneath the DSI SA was encountered at approximately 8 m bgs or deeper within the Clarendon Formation and between approximately 1m bgs and 10.8 m bgs within the LFA during the DSI. Fresh to brackish groundwater is hosted in the LFA and CFA.

The thickness of the CFA is currently undefined since boreholes did not reach the base of the aquifer. The CFA is interpreted to be a semi-confined aquifer hosted in predominantly fine sands of the lower unit. Monitoring wells installed during the DSI consistently had SWLs 3 - 9 m above groundwater strike and the base of the less permeable clays and silts of the upper unit in the Clarendon Formation (i.e. MW75 – MW80). The thickness of the LFA is interpreted to be approximately 10 – 15 m based on MW92, where the shale bedrock was encountered (refer to the borelogs presented in **Appendix E**). The LFA is predominantly an unconfined aquifer based on observations during the DSI. Standing water levels were similar to the observed groundwater strike at most locations in the Lowlands Formation (typically 1 - 8 m bgs). Exceptions were MW81 near Bensons Lane and MW99 on Cupitts Lane, which were semi confined by clays and silts.

The LFA and CFA are likely to be interconnected at depth approximately along the boundary of the upper terrace and lower floodplain terrace. Permeable silty sand and fine sand of the LFA is likely to be adjacent to the saturated sand of the lower unit in the Clarendon Formation (**Figures 8 - 10**).

5.3.2 Groundwater Recharge

Recharge of groundwater within the SA would occur through a combination of rain water infiltration and surface water runoff. Additional recharge from the Londonderry Clay and Rickabys Creek Gravel to the south and east of the Site may contribute to the CFA. Additional through flow directly from the CFA is likely to contribute to recharge also in the LFA.

Evidence of groundwater recharge has been identified on Site. Locations correlate with two identified source areas including MW70 and MW71 located adjacent to Hangar 54 and MW13 and MW33 located at Fuel Farm 2, refer to **Figure 11B** in **Appendix A** and **Table T2** in **Appendix B**.

A review of surface water observations and groundwater elevations in nearby wells within the LFA is provided in **Table 48** below.

Table 48 Comparison between creek depth and groundwater depth at selected locations in the LFA

Creek	SW location	Creek depth below surrounding ground surface (m) ^a	Nearest well	Groundwater Depth (mbgs)	Likelihood of SW-GW Interactions (condition) ^c
Cooleys Ck	SW16	4	MW97	4.58	yes (losing)
Rickabys Creek	SW023	approximately 8	MW92	7.0 ^b	yes (gaining)
Rickabys Creek	SW18	10	MW93	10.90	yes (losing)
Unnamed Drain	SW22	1.5	MW81	1.97	yes (losing)

Note:^a Depth to the water surface is based on observations during surface water sampling (**Appendix G**)^b Ground water strike observed during drilling - representative of the upper aquifer.^c Comment on gaining or losing condition is indicative only

Based on observations in **Table 48**, there is evidence that surface water and groundwater are interacting in Cooleys Creek (MW97), Rickabys Creek (MW93 & MW92) and the Unnamed Drain to the north of the Site (MW81). There are also indications that Cooleys Creek, the Unnamed Drain and Rickabys Creek were losing at the time groundwater elevations were measured in November 2017. A gaining condition was observed at MW92 at Rickabys Creek where the upper aquifer groundwater level was observed above the creek water level. Without continuous water level data the persistence of gaining or losing conditions in these water bodies cannot be accurately determined.

Hydrogeochemical data in groundwater provides additional support for a component of recharge from surface water into the LFA at Cooleys Creek (MW97) and the Unnamed Drain (MW81). An elevated Na/Cl ratio in groundwater at MW81 provides evidence for surface water infiltration to groundwater from the Unnamed Drain (greater than 1.0 in **Table T10**). Surface water infiltration to groundwater at Cooleys Creek is also supported by an elevated Na/Cl ratio as well as relatively high HCO₃, NO₃ and NH₃ concentrations at MW97. High HCO₃ suggests oxygenated surface water is infiltrating to groundwater while NO₃ and NH₃ suggest agricultural runoff in surface water is contributing to groundwater.

Pipers Plots for major ions within the LFA provide evidence for a component of surface water infiltration at MW81 (Unnamed Drain) and MW97 (Cooleys Creek) (LFA Piper Plot - **Appendix D**). Here, carbonate enrichment is indicated at Cooleys Creek. Similarly, depleted Ca²⁺, Mg²⁺ and Cl⁻ indicate some dilution from surface water recharge to groundwater at these locations (LFA Piper Plot - **Appendix D**).

A further indicator of possible surface water infiltration to groundwater at MW97 is the elevated detections of Manganese and Iron (refer to **Table T9** in **Appendix B**). These may be an indicator of pollution from anthropogenic sources.

5.3.3 Groundwater Elevation Contours

Depth to standing water in selected on-Site and off-Site monitoring wells was measured on 27 November 2017 and was used to estimate groundwater elevation contours within the CFA and LFA presented in **Figure 11** in **Appendix A**. The results are presented in **Section 4.4**.

Groundwater elevation for the CFA ranged from 9.45m AHD to the south west of the site (MW75) to 5.32 m AHD at the eastern edge of the Site (MW47). In the LFA groundwater elevations ranged from 5.55 m AHD near Bensons Lane (MW82) to -0.27 m AHD east of the Site near the Hawkesbury River (MW93).

5.3.4 Horizontal Hydraulic Gradients

Based on the gauging event data, the horizontal hydraulic gradient was estimated for the predominant flow directions across the SA (**Table 49** below).

Table 49 Horizontal Hydraulic Gradients

Selected Wells	Horizontal Separation (m)	Aquifer (s)	Flow Direction	Horizontal Gradient
MW80 to MW83	2200	CFA & LFA	NW	0.0016 m/m
MW75 to MW80	1500	CFA	NE	0.0012 m/m
MW96 to MW88	1000	LFA	NE	0.0035 m/m
MW95 to MW90	1750	LFA	NE	0.0025 m/m

Across the Clarendon Formation the gradient is generally flat (i.e. MW75 to MW80), however further downgradient to the north east this flattening is accentuated across the Rickabys Drop Zone within the LFA as indicated in **Figure 11** in **Appendix A**. Further downgradient of Rickabys Drop Zone near Cornwallis, the horizontal hydraulic gradient steepens towards the Hawkesbury River (MW96 – MW88). While the LFA horizontal gradient is variable, an average gradient of 0.0025 m/m can be assumed as representative for this formation. A representative horizontal gradient for the CFA is estimated at 0.0012 m/m.

5.3.5 Groundwater Composition as Evidence of Flow Direction

5.3.5.1 Total Dissolved Solids - Clarendon Formation Aquifer and Lowlands Formation

Groundwater within the CFA and LFA is generally fresh as indicated by the low total dissolved solids (TDS) concentrations in the majority of monitoring wells installed on- and off-Site. TDS concentrations are presented in **Table T9** in **Appendix B**.

5.3.5.2 Major Ion Composition

A total of 96 groundwater samples and 7 surface water samples were analysed for major ion composition (calcium, magnesium, sodium, potassium, sulfate, carbonate/bicarbonate and chloride) to help understand groundwater flow paths. The results are presented in Piper diagrams in **Appendix D**. The following observations are drawn from the diagrams:

- **Cation Composition** – The cation composition is dominated by sodium and the trend in the lower left triangular diagram indicates that more saline water is interacting with fresh water. Samples with high TDS are displayed on the lower right corner of the diagram. Monitoring wells where PFAS concentrations were reported as less than the laboratory LOR were generally lower in sodium than at wells at or near the inferred plume front (closer to the CFA).
- **Aquifer interaction** – Samples collected from locations within the LFA and CFA show relatively equivalent calcium and sodium concentrations, as well as chloride concentrations indicating that the aquifers are likely connected.

5.3.6 Hydraulic Conductivity Estimates

The hydraulic conductivity of the CFA and LFA was assessed by conducting slug tests at monitoring wells installed in the representative lithological units encountered during the DSI. The hydraulic conductivities of the different aquifers were also estimated using the Rosetta Model on the PSD results for samples collected during monitoring well installations. The hydraulic conductivity estimates are presented in **Section 4.4**.

- **LFA:** The upper portion of the LFA comprised of silt/clay/sand, and was intersected in most wells on the flood plain terrace. Representative hydraulic conductivity values of this upper portion of the LFA indicated from slug tests that values may range from 0.02 to 0.06 m/day. The coarser basal unit of produced a higher conductivity value as expected with of 3.35 m/day being representative for the deeper portion of the LFA. As discussed in **Section 5.1**, there is notable lateral and vertical lithology variation which would result a range of hydraulic conductivity's within the LFA.
- **CFA:** Slug testing and PSD estimates are 1-2 orders of magnitude higher that the fine grained upper portion of the LFA. The sandy nature of the lower unit of the CFA clearly represents the

main water bearing zone of the Clarendon Formation with slug tests indicating a representative hydraulic conductivity range of 2-5 m/day.

The estimated hydraulic conductivity for the LFA and CFA generally correspond with the interpreted geology. However, there is still uncertainty in the slug testing and PSD estimates due to the limited data set generated during the DSI. Additional slug tests would help to refine the results of the DSI.

5.3.7 Groundwater Flow Velocity Estimates

The groundwater flow velocity can be estimated based on Darcy's law:

$$v = K \cdot \frac{dh}{dl} \cdot \frac{1}{n_e}$$

Where:

v is the average linear groundwater velocity or the velocity of a water molecule

$\frac{dh}{dl}$ is the horizontal hydraulic gradient

n_e is the effective porosity which is sometimes referred to as mobile porosity.

The effective or mobile porosity affects the average linear groundwater velocity and has not been investigated at the Site. A nominal effective porosity value of 0.1 to 0.2 from literature values has been selected as representative for fine sands and silty sands encountered across the SA. Heterogeneity within the LFA and CFA may result in effective porosity values outside the above nominal values.

LFA – A representative hydraulic conductivity range for the upper portion of the LFA is 0.02 to 0.06 m/day, with a representative horizontal gradient of 0.0025 m/m. If the effective porosity is assumed to range between 0.1 and 0.2, the average linear groundwater velocity can be estimated to range from (0.02 m/day × 0.0025 m/m / 0.2 × 365 days/year) **0.09 m/year** to (0.06 m/day × 0.0025 m/m / 0.10 × 365 days/year) **0.55 m/year**.

CFA - A representative hydraulic conductivity range for the lower unit of the CFA is 2 to 5m/day with a representative horizontal gradient of 0.0012 m/m. If the effective porosity is assumed to range between 0.1 and 0.2, the average linear groundwater velocity can be estimated to range from (2 m/day × 0.0012 m/m / 0.2 × 365 days/year) **4.38 m/year** to (5 m/day × 0.0012 m/m / 0.10 × 365 days/year) **21.9 m/year**.

5.4 PFAS Groundwater Impacts and Fate and Transport

Groundwater sample results are presented in **Figures 16 to 18 in Appendix A**, and discussed in the following sections. The concentrations of PFAS in groundwater are described by the colours used in the figures. The interpreted extent of groundwater impacts is shown in **Figure 28 in Appendix A**.

5.4.1 Groundwater Impacts - On-Site

The works performed as part of the DSI have shown that the highest concentrations of PFAS was reported adjacent to identified potential PFAS source zones (refer to **Figure 27 in Appendix A**).

All monitoring wells sampled on the Base reported detections of PFAS with the exception of MW42 and MW43. The distribution of PFAS within groundwater at the Base is considered to be consistent with the findings of the historical AFFF review outlined in **Section 2.4**. The inferred extent of groundwater impact is shown on **Figure 28 in Appendix A**.

Relatively lower PFAS concentrations were reported in groundwater samples collected on the northern and eastern boundaries of Rickabys Drop Zone.

5.4.1.1 Former Fire Training Ground

The maximum PFOS + PFHxS concentration of 969 µg/L was reported in a sample collected from existing monitoring well MW40, located near the Former Fire Training Ground (refer to **Figure 27**). Groundwater samples collected to the north (MW79) and north east (MW59) of the Former Fire Training Ground reported concentrations of 0.69 µg/L and 0.35 µg/L respectively. Given that MW79 located to the north and MW59 is located to the north east of MW40 indicates that impacts to the

groundwater above the adopted human health screening level (0.07 µg/L) from the Former Fire Training Ground may extend over a significant area.

The groundwater from the Former Fire Training Ground is interpolated to flow in a northerly and north easterly direction within the Clarendon Formation Aquifer.

5.4.1.2 Former Fuel Farm 1

The maximum PFOS + PFHxS concentration of 94.6 µg/L was reported in a sample collected from existing monitoring well MW72, located north of Former Fuel Farm 1 (refer to **Figure 27**).

Concentrations ranging from 22.6 µg/L to 434 µg/L PFOS + PFHxS were reported in a series of wells extending to the south east of the Former Fuel Farm (MW47, MW50 to MW52, MW73 and MW74).

The groundwater from the Former Fuel Farm 1 is interpolated to flow in an easterly direction towards Rickabys Creek within the Clarendon Formation Aquifer.

5.4.1.3 Fuel Farm 2

The maximum PFOS + PFHxS concentration of 31.4 µg/L was reported in a sample collected from existing monitoring well MW32, located within Fuel Farm 2. Groundwater samples collected to the south (MW13) and south east (MW17) of Fuel Farm 2 reported concentrations of 1.31 µg/L and 6.09 µg/L respectively, indicates that impacts to the groundwater above the adopted human health screening level (0.07 µg/L) from Fuel Farm 2 may extend over a significant area.

The groundwater from Fuel Farm 2 is interpolated to flow in an easterly direction within the Clarendon Formation Aquifer.

5.4.1.4 Hangar 54

The maximum PFOS + PFHxS concentration of 21.5 µg/L was reported in a sample collected from existing monitoring well MW63, located adjacent Hangar 54. Groundwater samples collected to the north east (MW60 and MW61) of Hangar 54 reported concentrations of 3.71 µg/L and 2.45 µg/L respectively. Given that MW60 and MW61 are located between approximately 250 m from MW63, concentrations above the adopted human health screening level (0.07 µg/L) from Hangar 54 may extend over a significant area.

The groundwater from Hangar 54 is interpolated to flow in a north easterly direction within the Clarendon Formation Aquifer.

5.4.1.5 Sewage Treatment Plant (STP)

The maximum PFOS + PFHxS concentration of 15.2 µg/L was reported in a sample collected from existing monitoring well MW21 located within the STP. Groundwater samples collected to the north (MW22) and north east (MW23) of MW21 reported concentrations of 7.05 µg/L and 0.05 µg/L respectively. Given that MW22 is located adjacent the site boundary, concentrations above the adopted human health screening level (0.07 µg/L) may be migrating off-Site from the STP.

The groundwater from the STP is interpolated to flow in a north easterly direction within the Lowlands Formation Aquifer.

5.4.2 Groundwater Impacts - Off-Site

The highest off-Site concentrations occurred north west of the Site adjacent Dight St (max 6.31 µg/L PFOS + PFHxS at MW80) and adjacent Clarendon Street (max 0.61 µg/L PFOS + PFHxS at MW79 in duplicate sample 0902_QC183_171117).

The inferred extent of PFAS impacts are indicated to the north west, north and east of the Site as shown in **Figure 28** in **Appendix A**. The extent of PFAS impacts (shown in **Figure 28** in **Appendix A**) to the west of the Site, is considered to be conservative and based off only two data points (MW81 and BW002).

All monitoring wells installed along Cornwallis Lane and Cornwallis Road (MW82 to MW85 and MW87 to MW92), north and east of the Site reported PFAS concentrations less than the laboratory limit of reporting.

Samples collected from monitoring wells located hydraulically up gradient of the Base (MW75, MW76 and MW77) did not report concentrations of PFAS greater than the LOR with the exception of MW77 closest to the south western Base boundary.

An off-site PFAS detection within groundwater adjacent to Cooleys Creek (MW97) has been interpreted as not being connected to the main plume further to the south (**Figure 28** in **Appendix A**). Limited data between MW97 and the main plume as well as a PFAS non – detect at MW98 indicates that advective groundwater may not contribute to the impact observed at MW97. Further, the STP outfall discharges treated effluent at the confluence of Bakers Lagoon and Cooleys Creek, and surface water may be interacting with groundwater at monitoring well location MW97.

As discussed in **Section 5.3.2** it is possible that the nearby drain may be losing surface water to the groundwater at MW81. Due to the large distance between neighbouring monitoring wells MW81 has been included within the inferred PFAS Plume (refer to **Figure 28** in **Appendix A**).

The off-Site detections of PFAS close to the Site are generally consistent with advective groundwater transport along a hydraulic gradient, PFAS detections further from the Site (i.e. locations MW81, MW97 and BW002) are not supported by the groundwater flow velocity estimate calculated in **Section 5.3.7** and may be result of surface water interaction. Interpretative groundwater flow directions are **Figure 11** in **Appendix A**.

5.4.3 Implications of Sub-surface Conditions on the Extent of PFAS in Groundwater

The observed extent of PFAS detections in groundwater in the LFA may be partly influenced by the composition and fine grained nature of the saturated zone within the LFA (clays, silts and fine sand). The apparent lack of migration of PFAS via advective groundwater flow towards the northeast and east of the Site may be related to a combination of:

- Low permeability and subsequently low groundwater velocities ranging from 0.09 - 0.55 m/yr in the saturated zones observed in the DSI (**Section 5.3**)
- Possible increased retardation of PFAS via clay minerals or oxyhydroxides (**Section 2.9.2**).

The lack of coarse sand and gravel intersected during drilling within the LFA indicates that high permeability zones (which would enable greater PFAS migration rates) are possibly absent or located at greater depth within the LFA.

Soil samples collected from the mid screen of newly installed monitoring wells are presented in **Table 50** below.

Table 50 Mid Screen Cation Exchange Capacity, Total Organic Carbon and Iron

Location	Aquifer	Cation Exchange Capacity (meq/100g)	Average (meq/100g)	Total Organic Carbon (%)	Average (%)	Iron (mg/kg)	Average (mg/kg)
MW75	Clarendon Formation Aquifer	2.5	4.3	0.12	0.21	9,330	6,673
MW76		4.2		0.11		1,710	
MW79		7.3		0.49		8,210	
MW80		3.2		0.11		7,440	
MW84	Lowlands Formation Aquifer	6.4	6.85	0.06	0.21	16,600	10,220
MW88		3.0		0.10		5,710	
MW89		0.7		0.14		3,550	
MW93		15.4		0.78		13,800	
MW95		11.2		0.10		16,800	
MW99		4.4		0.05		19,800	

The cation exchange capacity and iron within the aquifer matrix was on average greater in the LFA compared to the CFA which may indicate that greater retardation of PFAS migration is occurring in the LFA than the CFA (refer to **Section 2.9.2**). The total organic carbon in the two aquifer matrices was approximately equal on average.

5.5 PFAS Nature and Extent in Surface Water and Sediment

5.5.1 Surface Water Topography and Drainage

As described in **Section 2.3.1**, the topography on-Site around operational and residential infrastructure is relatively flat to very slightly sloping toward the edge of the Clarendon Formation to the north west, north and north east (**Figure 4** in **Appendix A**). From this point there is a distinct drop in topography to the Richmond Lowlands (**Figure 3** in **Appendix A**) which directs surface water runoff from the Site to drain down toward Rickabys Creek and its tributaries.

The surface water swale drainage systems on-Site in Catchments C and D were upgraded in 2016 as described in **Section 2.3.5.2**. The design grades for the swale drains were described to be less than 1%, with several sections of the swales designed to be less than 0.3% (G Herman and Associates, 2016). Given that one of the key design objectives of the system was to remove pooled surface water within 48 hours of a rainfall event, it is assumed that standing surface water in Catchments C and D are unlikely to occur for prolonged periods following rainfall, which is consistent with observations during site works.

5.5.2 PFAS Migration to Surface Water

The primary identified mechanisms for PFAS migrating into the local surface water drainage network discussed in **Section 2.3.5.2** include:

- AFFF impacted surface water runoff from the Airfield Foam Cannon Testing Area in Catchment D discharging to the stormwater drainage network
- Surface water runoff leaching PFAS from the ground surface, soil or pavements (Catchments A, C and D) and discharging to the stormwater drainage network
- PFAS from Catchments A, C and D passing through the TWP and being discharged in treated effluent to the Sewage Treatment Plant and thence to the effluent lagoon and ultimately discharging to Bakers Lagoon.

5.5.3 Nature and Extent of Surface Water and Sediment PFAS Impacts

The following sections discuss the PFAS identified on and off-Site in surface water and sediment samples. The concentrations of PFAS in surface water and sediments are illustrated in **Figures 19 to 24** in **Appendix A** and described by the colours used in the figures. For example, the sum of PFOS and PFHxS is as follows:

- Less than LOR = less than the limit of reporting for the laboratory analysis
- Low = LOR to 0.7 µg/L (surface water), LOR to 0.3 mg/kg (sediment)
- Moderate = 0.7 to 10 µg/L (surface water), 0.3 to 10 mg/kg (sediment)
- High = > 10 µg/L (surface water), >10 mg/kg (sediment).

These descriptors are not specifically related to guidelines, with the exception of low (LOR to 0.7 µg/L) for water which is related to the recreational water use criteria. Rather, they represent a range of concentrations found for the DSI.

5.5.3.1 On-Site PFAS Concentrations

For surface water, the highest concentrations of PFAS was found:

- at SW001 (adjacent to the Airfield Foam Cannon Testing Area) in Catchment D
- at SW002 and SW003 in the open drain to the west of the STP (Catchment D)
- in the Settlement Pond (SW011, from Catchment C)

- at SW010 in the open drain on Rickabys Drop Zone (from Catchment C).

Elevated PFAS concentrations in sediments generally correlated with elevated surface water concentrations. Refer to **Figures 19 to 21** for surface water sampling locations and **Figures 22 to 24** for sediment sampling locations.

PFOS, PFOA and PFHxS were all reported at concentrations greater than the laboratory LOR, however trends were most distinct for PFOS and PFHxS. PFOA concentrations were often low and less informative for discerning extent and pathways of contamination. As such, the focus was placed on patterns of the sum of PFOS and PFHxS contamination.

5.5.3.1.1 Catchment A

Catchment A contains Fuel Farm 2 where runoff is captured and discharged to the constructed wetlands on Rickabys Drop Zone, before entering the Settlement Pond (**Figure 5 in Appendix A**). Two locations were sampled from this catchment.

Surface Water

- sum of PFOS and PFHxS concentrations in surface water samples (SW012 and SW013) were moderate
- PFOA concentrations were low.

Sediment

- sum of PFOS and PFHxS as well as PFOA concentrations in sediment samples (SD012 and SD013) were low.

Hence, it appears that surface water runoff from Fuel Farm 2 may be leaching and transporting PFAS from the ground surface, soil or pavement surfaces through the surface water network.

5.5.3.1.2 Catchment C

Catchment C is the largest catchment on-Site and contains multiple potential PFAS source zones, including the Fire Station (Building 291 – refer to **Figure 27 in Appendix A**). Runoff captured from this catchment discharges to the Settlement Pond (**Figure 5 in Appendix A**). Two locations were sampled from this catchment.

Surface Water

- sum of PFOS and PFHxS concentrations in surface water samples (SW010 and SW011) were high (up to 28.1 µg/L at SW010)
- PFOA concentrations were moderate at SW010 and low at SW011.

Sediment

- sum of PFOS and PFHxS concentrations in sediment samples (SD010 and SD011) were moderate
- PFOA concentrations were low at SD010 and SD011.

The surface water and sediment results suggest PFAS from the potential source areas identified in Catchment C may be leaching PFAS from the ground surface, soil or pavements, resulting in high concentrations in surface water and moderate concentrations in sediment downstream in the surface water network.

5.5.3.1.3 Catchment D

Catchment D is second largest catchment on-Site with surface water discharging off-Site to the north of the STP Settlement Ponds. This catchment contains the Former Fire Training Ground and the Airfield Foam Cannon Testing Area (**Figure 5 in Appendix A**). Three locations were sampled in Catchment D with the highest concentrations in surface water and sediment recorded in the SA.

Surface Water

- sum of PFOS and PFHxS concentrations in surface water samples were high (up to 83.9 µg/L at SW002)

- PFOA concentrations were high at SW001 and moderate at SW002 and SW003.

Sediment

- sum of PFOS and PFHxS concentrations were high at SD001 (39.6 mg/kg) and moderate at SD002 and SD003
- PFOA concentrations were moderate at SD001 and low at SD002 and SD003.

The surface water and sediment results from Catchment D suggest PFAS from the Airfield Foam Cannon Testing Area and other potential source areas in the catchment are leaching PFAS from the ground surface, soil or pavements, resulting in the highest concentrations in surface water and sediment observed on the Site.

5.5.3.1.4 Catchment G

Catchment G is located to north east of the Site and includes residential buildings, the hospital and grassed areas (**Figure 5 in Appendix A**). No PFAS source zones were identified in this catchment. One location was sampled in this catchment.

Surface Water

- sum of PFOS and PFHxS concentrations were moderate at SW014
- PFOA concentrations were low at SW014.

Sediment

- sum of PFOS and PFHxS as well as PFOA concentrations were low at SD014.

Hence, despite the catchment not containing any identified PFAS source zones, it appears that PFAS compounds used at potential PFAS source zones within other catchments have been transported to Catchment G through processes such as flooding, resulting in moderate concentrations in surface water and sediment.

5.5.3.1.5 Sewage Treatment Plant

The STP is located to the north of the Base and is not in a defined Site catchment, however is considered to be a potential PFAS source area (**Figure 5 in Appendix A**). Surface water from the settlement ponds discharges off-Site to Bakers Lagoon. One surface water sample was collected from the settlement pond. A co-located sediment sample was not able to be safely obtained.

- sum of PFOS and PFHxS concentrations were low at SW037
- PFOA concentrations were low at SW037.

These results indicate PFAS are migrating through the Sewage Treatment Plant system and are discharging off-Site.

5.5.3.2 PFAS Concentrations off-Site

For surface water, the highest concentrations of PFAS off-Site were found:

- At SW009 in Rickabys Creek
- At SW032 in Bakers Lagoon.

Similar to on-Site, PFAS concentrations in sediment were generally correlated to surface water concentrations. Refer to **Figures 19 to 21** for surface water sampling locations and **Figures 22 to 24** for sediment sampling locations.

Although PFAS concentrations in surface water were reported above the LOR at locations upstream of the Site (for example, SW020 and SW024), there are no plausible pathways which have been identified for Site runoff to impact these areas. Therefore impacts may be attributed to upstream land uses or activities and therefore detections of PFAS may be representative of '*background*' conditions.

5.5.3.2.1 Rickabys Creek

Upper Rickabys Creek

Two locations on Rickabys Creek upstream of surface water discharge points from the Site were sampled. PFAS was detected at concentrations above the LOR in surface water and the highest PFAS concentration off-Site in sediment was recorded in this catchment (SD019). In summary:

Surface Water

- sum of PFOS and PFHxS as well as PFOA concentrations were low at both locations (SW019 and SW020)

Sediment

- PFAS was not detected in sediment at SD020
- sum of PFOS and PFHxS was low at SD019 (0.0032 mg/kg)
- PFOA concentrations were low at SD019.

The surface water and sediment results suggest PFAS is present within the Rickabys Creek Catchment upstream of the off-Site discharge points (refer **Figure 5** in **Appendix A**).

Tributaries of Rickabys Creek

Ten locations on the north western tributaries of Rickabys Creek were sampled, including Pughs Lagoon (SW035) at the headwaters of the catchment and two locations (SW033 and SW034) on a private property north of the Site. PFAS was detected above the LOR at all surface water locations sampled, including SW022, SW033 to SW036 which are upstream of the surface water discharge points from the Site (**Figure 5** in **Appendix A**). PFAS concentrations were detected above the LOR in nine of the ten sediment sample locations. In Summary:

Surface Water

- sum of PFOS and PFHxS concentrations were moderate at location SW015 and were low at the remaining locations
- PFOA was not detected at Pughs Lagoon (SW035), or at SW005 and SW033. PFOA concentrations were low at the remaining locations.

Sediment

- PFAS was not detected in sediment at Pughs Lagoon (SD025)
- sum of PFOS and PFHxS concentrations were low at the remaining locations
- PFOA concentrations were low at SD004, SD007 and SD015. PFOA was not detected at the remaining locations.

The surface water results indicate that PFAS is present within the tributaries of Rickabys Creek upstream of the off-Site discharge points (refer to Figure 5 in Appendix A). PFAS compounds present upstream of these discharge points are likely to be the result of catchment activities not related to the Site and are considered to be representative of background conditions. Downstream from the off-Site discharge points the surface water and sediment results indicate that PFAS may have migrated from catchments on-Site through the surface water network resulting in impacts to the tributaries of Rickabys Creek.

Lower Rickabys Creek

Four locations in Lower Rickabys Creek were sampled with all locations reporting PFAS above the LOR, including the highest off-Site PFAS concentration in surface water (SW009). In summary:

Surface Water

- sum of PFOS and PFHxS concentrations were high at location SW009 (21.3 µg/L) and were low at the remaining locations (SW008, SW018, SW023)
- PFOA was not detected at SW018 and concentrations were low at the remaining locations

Sediment

- sum of PFOS and PFHxS concentrations were low at all locations (SD008, SD009, SD018 and SD023)
- PFOA was not detected at SD008 and SD023. PFOA concentrations were low at SD009 and SD018

Surface water results suggest PFAS may be migrating from potential source areas and catchments on-Site through the surface water network resulting detectable concentrations in surface water off-Site and downstream in Rickabys Creek.

5.5.3.2.2 Cooleys Creek

Three locations in the Cooleys Creek catchment were sampled, including Bakers Lagoon at the headwaters of the catchment which receives treated effluent from the on-Site STP Settlement Ponds.

In Summary:

Surface Water

- PFAS was not detected at locations SW016 and SW017
- sum of PFOS and PFHxS concentrations were moderate and PFOA concentrations were low in Bakers Lagoon (SW032).

Sediment

- sum of PFOS and PFHxS concentrations were low at all locations (SD016, SD017 and SD032)
- PFOA concentration was low at SD032 and not detected at the remaining locations (SD016 and SD017).

Surface water concentrations at sample location SW032 indicate that PFAS is present in Bakers Lagoon. Potential sources, including the STP, have been identified within the vicinity of Bakers Lagoon. Identified potential sources in the area are being investigated as part of the HHRA.

5.5.3.2.3 Hawkesbury River

Eight locations within the Hawkesbury River were sampled. PFAS was detected above the LOR in seven of eight locations sampled in surface water and two of eight locations in sediment. In summary:

Surface Water

- PFAS was not detected at location SW027
- sum of PFOS and PFHxS concentrations were low at the remaining locations
- PFOA was not detected at any sample location on the Hawkesbury River

Sediment

- PFAS was not detected in sediment at SD024, SD026 and SD028 to SD031
- sum of PFOS and PFHxS concentrations were low at locations SD025 and SD027
- PFOA was not detected at any sample location on the Hawkesbury River

Surface water results indicate PFAS is present in the Hawkesbury River within the SA, including the furthest upstream sample location at North Richmond (SW024). Given that PFAS impacted surface water has been identified at the off-Site discharge points (refer to **Figure 5 in Appendix A**) migration from the Site may be contributing to reported concentrations in the Hawkesbury River.

5.5.4 Spatial Variability in Surface Water Concentrations

The highest PFAS impacts on-Site were found to be at locations of discharge from Catchments C and D (**Figure 5 in Appendix A**), which are closely related to the potential PFAS source zones described in **Figure 27 in Appendix A**. Within Catchments C and D, PFAS concentrations in surface water and sediment do not appear to be decreasing with distance from the potential PFAS source zones with the concentration of the sum of PFOS and PFHxS found to be within a similar order of magnitude.

The spatial variability of PFAS off-Site was investigated by comparing the sum of PFOS and PFHxS concentrations in surface water with distance from Site. This is discussed below, in turn, for Rickabys Creek and its main tributary, Cooleys Creek and the Hawkesbury River with reference to **Figure 21 in Appendix A**.

5.5.4.1 Rickabys Creek

PFAS was detected upstream of the main off-Site discharge points (SW003 and SW009) into Rickabys creek and its north western tributaries. As discussed in **Section 5.6.3.2** above, no plausible surface water pathway exists for off-Site runoff to impact areas upstream of these locations. **Section 2.7** presented a series of off-Site locations within the Rickabys Creek catchment where PFAS may have been used historically (refer to **Figure 30 in Appendix A**) and may explain the detections in these areas. Additionally, the concentration of the sum of PFOS and PFHxS at sample location SW020 is consistent with the results reported by GHD in a preliminary investigation in 2016 (GHD, 2016), therefore the concentration recorded may be representative of background conditions.

The highest concentration of the sum of PFOS and PFHxS in Rickabys Creek and its north western tributaries were found to be at the main off-Site discharge points (76.1 µg/L at SW003 and 21.3 µg/L at SW009). At SW015 and SW008, the closest downstream sample locations from the discharge points listed above, the concentration decreased by approximately two orders of magnitude (0.88 and 0.37 µg/L respectively). As distance increases downstream on Rickabys Creek, the concentrations remain within a similar order of magnitude, with the greatest reduction observed at SW018 (0.08 µg/L) upstream of the junction with the Hawkesbury River.

5.5.4.2 Cooleys Creek

As described in **Section 2.3.5.3**, Bakers Lagoon receives treated effluent discharge from the on-Site STP. PFAS was detected at the discharge point of the Settlement Ponds with the sum of PFOS and PFHxS found to be 0.18 µg/L. Moderate level detections were recorded in Bakers Lagoon (4.75 µg/L at SW032) indicating that there may be temporal variability associated with sewage treatment plant discharge or there are other mechanisms resulting in the higher concentrations observed.

Downstream from Bakers Lagoon two locations were sampled in Cooleys Creek. Surface water from SW016 and SW017 were obtained during dry conditions from pooled surface water that was discontinuous within the creek and may have been local catchment rainfall rather than discharge from Bakers Lagoon. Therefore the surface water results may not be representative of conditions when Bakers Lagoon is flowing into Cooleys Creek.

5.5.4.3 Hawkesbury River

PFAS was detected above the LOR at seven of the eight surface water sample locations on the Hawkesbury River, including the furthest upstream location adjacent to North Richmond. The sum of PFOS and PFHxS concentrations ranged from less than the LOR (SW027) to 0.16 µg/L (SW029). Similar to Rickabys Creek, no plausible surface water pathway or mechanism of dispersal can explain the association between the PFAS detection in the Hawkesbury at North Richmond and the Site. With the exception of sample location SW029, overall the detections of PFAS are low and only marginally above the detection limit (0.01 µg/L). This suggests that PFAS detections may be attributed to activities further up in the catchment (refer to **Figure 30 in Appendix A**) and concentrations observed may be representative of background conditions. However, given the location of SW029 within the SA, the concentration observed may be attributed to PFAS identified within Cooleys Creek Catchment (Bakers Lagoon), which is upstream from this location.

5.5.5 Flooding and PFAS Movement

Figure 31 in Appendix A depicts the Hawkesbury River flood events that have occurred since AFFF was in use on-Site from 1976 (refer to **Section 2.4**). Flood levels suggest the STP as well as the main discharge points off-Site (SW003 and SW009) have been impacted by multiple flood events since 1978.

Flooding could contribute to the dispersal of PFAS in the following ways:

- Local runoff could transport PFAS from the Site:

- via the tributaries of Rickabys Creek to the north of the Site, localised flooding adjacent to the drains could disperse PFAS onto the Richmond Lowlands
- via Rickabys Creek to the east of the Site, which might back up causing localised flooding adjacent to the Creek.
- Significant Hawkesbury River flooding could disperse PFAS impacts detected in Bakers Lagoon, Tributaries of Rickabys Creek and Rickabys Creek throughout the Richmond Lowlands

As a potential mechanism for dispersing PFAS, large flooding events on the Richmond Lowlands are broad in spatial extent and could contribute to low concentrations of surface water and sediment contamination across a broad area.

5.5.6 Windblown Transport of PFAS

The potential for windblown transport of PFAS entrained on soil particles or in mists is considered to be relatively low, as on-Site source areas are either covered by hardstand or well-maintained grass cover. Specific activities that could have contributed to windblown transport of PFAS in the past include:

- Firefighting training, testing or emergency response
- During construction/earthworks, however standard practice requires dust suppression.
- Irrigation mist from surface water bodies.

These shorter term activities, which in some instances are once off activities are likely to result in a lower mass of PFAS leaving the site, when compared to the mass of PFAS likely to have migrated in surface water and groundwater continuously over a longer duration.

5.6 Data Gaps

Data gaps identified as part of this DSI and are outlined below:

- Potential off-Site migration may be occurring through the lower portion of the CFA and LFA aquifers and basal gravels (if present). Monitoring wells installed during the DSI primarily targeted the upper portion of the aquifers, noting that MW92 installed east of the Site targeted the base of the LFA and analytical results for PFAS were less than the laboratory LOR
- Reported concentrations of PFAS in groundwater north west of the Site, specifically around MW81. The preliminary CSM developed in the SAQP (AECOM 2017a) indicated that surface and groundwater flow was predominantly to the north east, where the DSI was focussed
- Surface water bodies may be losing PFAS impacted water to the aquifer(s), subsequently increasing the interpreted extent of the groundwater plume
- The nature and extent of PFAS impacts in soil at identified source areas have not been fully delineated (noting this was not an objective of the DSI)
- Field PFAS sorption coefficients were unable to be calculated due to the limited PFAS detections in mid screen soil, these data would be valuable for development of any future groundwater model to assess the fate and transport of PFAS in groundwater
- Temporal variation in data, noting that additional data will be generated as part of the upcoming Human Health and Ecological Risk Assessments to add to that generated during the DSI
- The potential for precursors occurring in either 3M Lightwater or in Ansulite to act as ongoing secondary sources of PFAAs has not been assessed.

The requirement for future monitoring and additional investigation works will be evaluated in the development of the PMAP. In the event that monitoring or additional investigation works are considered warranted, further evaluation of trends (spatial, temporal and seasonal) could be undertaken utilising an enhanced dataset.

6.0 Conceptual Site Model

6.1 Introduction

6.1.1 Purpose

The purpose of the CSM is to provide an understanding of the nature and extent of PFAS impacts and migration mechanisms, and the exposure pathways by which identified receptors may be exposed to PFAS from the Site. The CSM also serves as a framework to assess potential risks to human and ecological receptors.

The CSM discussed below is a dynamic tool that is intended to be continually challenged and updated throughout the assessment process as new information becomes available. Its development is an iterative process. At the end of each phase of intrusive investigation or where key pieces of information become available, the CSM will be refined, as required. The CSM discussed below provides a description of the current understanding of the status of PFAS source-pathway-receptor linkages. Refer to **Figures 25 and 26 in Appendix A** for graphical representations of the CSM.

6.1.2 Essential Elements of a CSM

In accordance with National Environment Protection (Assessment of Contamination) Measure (ASC NEPM, 2013), the CSM should identify complete and potentially complete exposure pathways between the known or potential source and the receptor.

In this case, the potential risks to receptors are evaluated based on three components:

- **Source:** A potentially hazardous substance that has been released into the environment
- **Exposure pathway:** A mechanism by which receptors can become exposed to the source or derivatives of the source
- **Receptor:** A person, ecosystem or ecological member potentially at risk of experiencing an adverse response following exposure to the source or derivatives of the source.

If all three components are present in an exposure scenario, the source-pathway-receptor linkage is considered complete and a receptor can be exposed and there is a potential risk. However, if one of these three is missing, the linkage is incomplete and it is considered that there is no risk.

6.2 Summary of Sources of Contamination

The following activities on or near the Site are considered to have resulted in PFAS impacts to soil, sediment, surface water and/or groundwater (see **Figures 25 and 26 in Appendix A**).

6.2.1 Primary Sources

6.2.1.1 On-Site

- AFFF use associated with the Former Fire Training Ground (Contaminated Sites Register (CSR) Number: SW0247)
- AFFF use associated with the Airfield Foam Cannon Testing Area (CSR Number: SW002)
- AFFF use associated with aircraft accidents and other emergency response situations
- AFFF spills/leakage during storage and handling at the Fire Station Building (CSR Number: SW0266)
- Potential discharge of AFFF from fire suppression systems at Hangar 54 and leakage from tanks storing fluids containing PFAS
- Potential AFFF use associated with Fuel Farm 2 (CSR Number: SW0249) and leakage from tanks storing fluids containing PFAS
- Potential AFFF use associated with Former Fuel Farm 1 (current Tanker Parking Area, CSR Number: SW003) and leakage from tanks storing fluids containing PFAS.

6.2.1.2 Off-Site

Potential off-Site sources are presented in **Section 2.7** and **Figure 12** in **Appendix A** and are summarised below:

- Waste water treatment plants, located at North Richmond, Wallacia and Winmalee
- Water Recycling Plants, located at Picton, West Camden, Penrith and Richmond
- Fire and Rescue NSW sites including; Cranebrook, Richmond, Windsor, South Windsor, Regentville and Penrith Fire Stations
- TestSafe and Fire and Rescue NSW, located in Londonderry
- Recycled water use areas including; the University of Western Sydney Campus, Richmond Golf Course and Windsor Golf Course
- Paper manufacturer, located on Mileham St Windsor
- Waste facilities located in South Windsor and Londonderry
- Factory fire responded to by Base fire fighters in Mulgrave.

6.2.2 Secondary Sources

6.2.2.1 On-Site

- Infiltration of surface water containing PFAS through unlined swale drains to underlying and surrounding groundwater
- Leakage or overflow of water containing PFAS at the TWP (CSR Number: SW0263) and leakage from the trade waste drainage network. Infiltration of water containing PFAS at the STP (CSR Number: SW0057) in pipelines leading to the sewage treatment plant and at the associated effluent lagoons
- Soil in the aquifer zone with sorbed PFAS
- Shallow soil with adsorbed PFAS from surface run off/flooding
- Sediments containing PFAS in drains.

6.2.2.2 Off-Site

- Soil in the aquifer (saturated) zone with sorbed PFAS
- Surface water in the Hawkesbury River containing PFAS
- Shallow soil with sorbed PFAS from surface run off/flooding
- Sediments containing PFAS in drains / creeks
- Shallow soil with sorbed PFAS from surface run off/flooding
- Biota that have been exposed to PFAS and, as a result of bioaccumulation, have retained PFAS in their system.

6.3 Migration Mechanisms

The following migration mechanisms may have contributed to the transport of PFAS from the Site (see **Figure 26** in **Appendix A**):

- Discharge or spilling of AFFF at the ground surface, or leakage from infrastructure
- Sorption of PFAS to soil in areas where AFFF was historically used
- Localised dispersion of AFFF with the wind during historical application
- Wind dispersion of PFAS impacted fine grained soil and dust, if disturbed by excavation

- Surface water runoff containing PFAS flowing into swale drains and subsequent off-Site migration via the stormwater network, Rickabys Creek and Cooleys Creek, as well as sorption in soils and sediments in the drains/creeks
- Infiltration of PFAS impacted surface water from drains or water bodies and effluent treatment ponds associated with the STP under 'losing' conditions, i.e. when water elevations in surface drains are higher than groundwater table
- Floodwater spilling over drains in some areas when capacity is exceeded and depositing PFAS impacted runoff onto adjacent soil and vegetation, and potential infiltration to groundwater as water levels fall
- Leaching of PFAS from soil and sediments in drains and infiltration to shallow groundwater in areas where AFFF was historically used
- Lateral and vertical migration of PFAS impacted groundwater under the influence of groundwater flow and PFAS dispersion. It is noted that groundwater abstraction such as construction dewatering or irrigation bores can influence contaminant migration in the aquifer as well as potentially creating secondary contamination of soil, sediment, surface water and groundwater where it is discharged however data collected to date indicates that this is likely to be minimal within the SA
- Sorption of PFAS to soil below the groundwater table during migration via groundwater. Sorption to soil slows down the migration of PFAS, however sorbed PFAS may continually diffuse back into groundwater and act as a secondary source depending on conditions
- PFAS impacted surface water ultimately discharging to the Hawkesbury River via Rickabys Creek and Cooleys Creek.

6.4 Exposure Pathways

The following potential exposure pathways have been identified (see **Figures 25 to 26 in Appendix A**):

- Human consumers of food grown using PFAS impacted surface water or groundwater for irrigation
- Consumption of seafood caught from PFAS impacted surface water
- Persons incidentally ingesting PFAS impacted soil and dermal contact with PFAS impacted soil
- Persons in direct contact / incidental ingestion with / of PFAS impacted surface water during irrigation or recreational activities
- Persons drinking PFAS impacted abstracted groundwater (or surface water connected to groundwater) from residential bores (Considered unlikely at present based on results of the water use survey)
- Persons incidentally ingesting groundwater / surface water via irrigation
- Persons incidentally ingesting and /or in direct contact with PFAS impacted sediment
- Ecological receptors in direct contact with PFAS impacted soil, sediment and surface water
- High trophic level terrestrial ecological receptors (e.g. eagle eating fish), small quantities of livestock and domestic pets exposed to surface waters and limited bore water.

As PFAS have the potential to bioaccumulate, human and ecological receptors can be exposed via multiple pathways.

6.5 Potential Receptors

The following potential receptors have been identified (see **Figures 25 to 26 in Appendix A**) and will be discussed in detail in the 2018 Off-Site HHRA and 2018 ERA. It is noted that the proposed HHRA will focus on off-Site Receptors only.

6.5.1 On-Site Receptors

- Childcare Centre (The Blue House OHSC, located on Canberra Avenue, RAAF Base Richmond)
- On-Site personnel who work at the Base. This is considered to encompass all personnel who undertake training or other operational works at the Site facility
- Residents who live on the Base (including adults, children and infants)
- On-Site intrusive maintenance workers (e.g. involving excavation of soil) who may conduct infrequent maintenance works on underground services or non-intrusive maintenance activities at the Site (i.e. personnel who maintain the gardens and grassed areas at the Site)
- Visitors to the Base who stay for a short period and are not frequently present at the Site (e.g. people who attend training or short term contractors).

6.5.2 Off-Site Receptors

- Recreational users of publically accessible surface waters
- Residents within the off-Site SA (including adults, children and infants)
- Commercial workers undertaking intensive plant agriculture (turf farming), market gardens and orchards
- Human consumers of aquatic biota (seafood) and other food exposed to PFAS impacted media (including soil, sediment and water) who live within the SA
- Livestock watered from abstraction bores
- In excess of 140 licence holders located between Windsor and Richmond may extract surface water from the Hawkesbury River (confirmed with NSW DPI via email correspondence on 30 January 2018).

6.5.3 Potential Ecological Receptors

Potential ecological receptors will be identified during the ERA. The list of potential receptors will include flora and fauna identified within terrestrial and aquatic ecosystems.

6.6 Summary

A summary of the CSM for both on- and off-Site (including linkages between sources, exposure pathways and receptors) is provided in **Table 51** and **Table 52**, and also presented in **Figures 25** and **26** in **Appendix A**.

The CSM indicates if a Source (S) - Pathway (P) and – Receptor (R) is:

- Complete – A complete linkage is considered to exist where:
 - The DSI has reported detectable concentrations of PFAS for a specific media, and
 - There is a confirmed exposure pathway (e.g. swimming in surface water).
- Potentially complete - A potentially complete linkage is considered to exist where:
 - The DSI has reported detectable concentrations of PFAS for a specific media, and
 - There is a suspected exposure pathway (e.g. incidental ingestion of soil), or
 - Where an exposure pathway exists, but the environmental media has not been specifically analysed to date.
- Incomplete – A complete linkage is not considered to exist and / or there is currently no identified complete pathway (e.g. groundwater for drinking water).

The CSM presented herein is based on the current uses of the land within the SA and does not consider future pathways allowable under the current land use (e.g. installation of a groundwater drinking bore).

Table 51 Conceptual Site Model – On-Site

Primary Source	Secondary Sources	Transport Mechanisms	Exposure Pathways	Exposed Population Characterisation / Receptor	Linkages
<p>On-Site areas where PFAS containing AFFF has been discharged or spilt to the environment.</p> <p>PFAS soaks into soil and/or infrastructure from where it can be eroded as sediment or leached by rainwater or flood water and migrate to groundwater, or dissolve in surface water runoff and potentially travel to affect other media.</p>	PFAS impacted shallow soil (<2.0 m).	Water and wind erosion and atmospheric dispersion of soil and dust. Excavation and re-location of soil during construction activities.	Human health: Incidental ingestion of soil on-Site.	Commercial / industrial	Complete (during intrusive works)
			Residential (including child care)	Potentially complete	
		Human health: Direct contact with soil on-Site.	Commercial / industrial	Complete (during intrusive works)	
	PFAS impacted groundwater.	Groundwater and / or surface being pumped and used for irrigation can result in detectable concentrations in soil.	Ecological	Residential (including child care)	Potentially complete
				Ecosystem	Complete
				Human health: Incidental ingestion of groundwater; via extraction from bore, irrigation or encountering during excavation works	Commercial / industrial
Human health: Direct contact of groundwater, via extraction from bores	Groundwater transport in shallow aquifer.	Human health: Direct contact of groundwater, via extraction from bores	Residential	Incomplete	
			Commercial / industrial	Incomplete	
			Residential (including child care)	Incomplete	

Primary Source	Secondary Sources	Transport Mechanisms	Exposure Pathways	Exposed Population Characterisation / Receptor	Linkages
		Groundwater mixing with surface water on-Site.	Human health: Drinking and direct contact with surface water (connected with groundwater)	Commercial / industrial Residential (including child care)	Incomplete Incomplete
			Ecological	Ecosystem	Complete
		Groundwater being pumped and used for irrigation.	Human health: Direct contact of groundwater, via extraction from bore, irrigation	Commercial / industrial Residential (including child care)	Incomplete Incomplete
			Ecological	Ecosystem	Complete
	PFAS impacted surface water.	Surface water transport; in drains and on ground surface on-Site.	Human health: Incidental ingestion of surface water	Commercial / industrial Residential (including child care)	Potentially complete (during intrusive works) Incomplete
			Ecological	Ecosystem	Complete
		Infiltration/mixing to shallow groundwater.	Human health: Direct contact with groundwater, via extraction from bores or encountering during excavation works	Commercial / industrial Residential (including child care)	Potentially complete (during intrusive works) Incomplete
			Ecological	Ecosystem	Complete

Primary Source	Secondary Sources	Transport Mechanisms	Exposure Pathways	Exposed Population Characterisation / Receptor	Linkages
		Surface water being pumped and used for irrigation.	Human health: Direct contact with surface water, via extraction from dam, river, drain or creek	Commercial / industrial	Incomplete
				Residential (including child care)	Incomplete
	PFAS impacted sediment.	Dispersion via surface water or via drain maintenance activities.	Human health: Incidental ingestion of sediment on-Site.	Commercial / industrial	Complete ¹
				Residential (including child care)	Potentially complete
			Human health: Direct contact of sediment on-Site.	Commercial / industrial	Complete ¹
		Ecological	Ecosystem	Complete	
		Human health: Direct contact of sediment on-Site impacted by groundwater (extracted via bore) or surface water	Commercial / industrial	Complete ¹	
				Residential (including child care)	Potentially complete

Note: 1 – As previously noted, the HHRA will focus on off-Site receptors only

Table 52 Conceptual Site Model – Off-Site

Primary Source	Secondary Sources	Transport Mechanisms	Exposure Pathways	Exposed Population Characterisation / Receptor	Linkages
PFAS soaks into soil and/or infrastructure on-Site from where it can be eroded as sediment or leached by rainwater or flood water and migrate to groundwater, or dissolve in surface water runoff and potentially travel to affect other media.	PFAS impacted shallow soil (<2.0 m).	Groundwater and / or surface being pumped and used for irrigation can result in detectable concentrations in soil.	Incidental ingestion of soil off-Site.	Residential	Potentially complete
				Recreational	Potentially complete
				Commercial (including horticulture)	Potentially complete
			Direct contact with soil off-Site.	Residential	Potentially complete
				Recreational	Potentially complete
				Commercial (including horticulture)	Potentially complete
			Ecological	Ecosystem	Complete
		Water and wind erosion and atmospheric dispersion of soil and dust. Excavation and re-location of soil during construction activities.	Human health: Incidental ingestion of soil off-Site.	Commercial (including horticulture)	Complete (during intrusive works)
			Residential	Potentially complete	
	Human health: Direct contact with soil off-Site.		Commercial (including horticulture)	Complete (during intrusive works)	
	Residential		Potentially complete		
		Ecological	Ecosystem	Complete	
	PFAS impacted groundwater.	Groundwater transport in shallow aquifer.	Human health: Incidental ingestion of groundwater; via extraction from bore, irrigation	Residential	Incomplete
				Commercial (including horticulture)	Potentially complete

Primary Source	Secondary Sources	Transport Mechanisms	Exposure Pathways	Exposed Population Characterisation / Receptor	Linkages
			Human health: Ingestion of groundwater, via extraction from bores.	Residential Commercial (including horticulture)	Incomplete Incomplete
		Groundwater mixing with surface water off-Site.	Human health: Drinking and direct contact with surface water (connected with groundwater)	Residential Commercial (including horticulture)	Incomplete (drinking), Potentially complete (direct contact) Incomplete (drinking), Potentially complete (direct contact)
			Ecological	Ecosystem	Complete
		Groundwater being pumped and used for irrigation.	Human health: Direct contact of groundwater, via extraction from bores.	Residential Commercial (including horticulture)	Incomplete Incomplete
	Terrestrial biota.	Harvesting.	Ingestion of terrestrial organisms (including fruit and vegetables).	Residential	Potentially complete
	Aquatic biota.	Harvesting	Ingestion of seafood	Residential	Potentially complete
				Recreational	Potentially complete

Primary Source	Secondary Sources	Transport Mechanisms	Exposure Pathways	Exposed Population Characterisation / Receptor	Linkages
	PFAS impacted surface water.	Surface water transport; in drains and on ground surface off-Site (including Hawkesbury River).	Human health: Incidental ingestion of surface water	Commercial (including horticulture)	Incomplete
				Residential	Complete ¹
				Recreational	Complete ¹
			Human health: Direct contact with surface water	Residential	Complete ¹
			Recreational	Complete ¹	
			Ecological	Ecosystem	Complete
		Infiltration/mixing to shallow groundwater.	Human health: Direct contact with groundwater, via extraction from bores, or irrigation	Residential	Incomplete
			Commercial (including horticulture)	Incomplete	
		Surface water being pumped and used for irrigation.	Human health: Direct contact with surface water, via extraction from dam, river, drain or creek (off-Site).	Commercial (including horticulture)	Complete ¹
			Residential	Potentially complete	
PFAS impacted sediment.	Dispersion via surface water or via drain maintenance activities.	Human health: Incidental ingestion of sediment off-Site.	Commercial (including horticulture)	Complete ¹	
			Residential	Potentially complete	
			Recreational	Complete ¹	

Primary Source	Secondary Sources	Transport Mechanisms	Exposure Pathways	Exposed Population Characterisation / Receptor	Linkages
			Human health: Direct contact of sediment	Commercial (including horticulture)	Complete ¹
				Residential	Potentially complete
				Recreational	Complete ¹
			Ecological.	Ecosystem	Complete
	PFAS impacted pore water in sediments ²	Surface water transport; in un-lined drains and surface water off-Site.	Human health: Incidental ingestion of surface water.	Commercial / industrial	Potentially complete
				Residential	Potentially complete
				Recreational	Potentially complete
			Ecological	Ecosystem	Complete ¹

Note: 1 – As previously noted, the HHRA will focus on off-Site receptors only
 2 - Pore water will be assessed during the upcoming HHRA for the Site.

7.0 Conclusions

The extent of PFAS at source areas on the Site has been evaluated through a historical AFFF review, groundwater sampling and limited soil sampling (at the STP). The works completed as part of the EWP and DSI have identified the following as PFAS source zones on the Site:

- The Former Fire Training Ground
- Hangar 54
- Former Fuel Farm 1
- Fuel Farm 2
- The STP.

Additional potential PFAS source zones have been identified in the historical AFFF review, and are presented on **Figure 27** in **Appendix A**. It is possible, given the long history of AFFF use at the Site that further source zones may be present which have not been identified during the DSI.

Secondary PFAS source zones are likely to have developed where PFAS impacted water has migrated or been concentrated and can leach to groundwater. Locations include: overflows and leakage at the STP and the TWP, as well as the underground and open drainage networks both on and off-Site.

The multiple on-Site sources have contributed to PFAS presence in the Clarendon Formation Aquifer which extends into the Lowlands Formation Aquifer. The interpreted extent of PFAS in groundwater indicates that the PFAS plume is approximately 2 km long (from southern extent to the northern extent), and 5 km wide (across the axis of migration).

All major on-Site drainage systems sampled during the DSI were found to contain PFAS, additionally PFAS has been detected at all locations where surface water discharges from the Site. These locations include:

- Runoff from Catchments D and G (north and north west of the Site) which discharge off-Site into tributaries of Rickabys Creek on the Richmond Lowlands
- Runoff from Catchments A and C (runoff from the south and east of the Site) which discharge off-Site into Rickabys Creek
- Treated effluent from the on-Site STP which discharges off-Site to Bakers Lagoon.

Ultimately, all surface water discharged into major drainage networks and creeks from the Site flow towards the Hawkesbury River.

The CSM has been refined based on the analytical results of data collected from multiple media within the SA, the results of the water use surveys received to date, and information received from NSW DPI regarding licenced users of water from the Hawkesbury River. Within the SA, surface water bodies are used for irrigation and this pathway has been included in the CSM.

Both the refined CSM, data generated in the DSI and additional data collected following the DSI will be used to inform the Human Health Risk Assessment and Ecological Risk Assessment. The DSI, HHRA and ERA will ultimately inform the scoping and planning of future management options for the Site.

8.0 References

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9.0 Limitations

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