DEPARTMENT OF DEFENCE

RAAF BASE TOWNSVILLE - ECOLOGICAL RISK ASSESSMENT (ERA)

VOLUME 1: MAIN REPORT

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PUBLIC

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RAAF Base Townsville - Ecological Risk Assessment (ERA)
Volume 1: Main Report

Department of Defence

WSP
Level 3, Northbank Plaza,
69 Ann Street
Brisbane QLD 4000
GPO Box 2907
Brisbane QLD 4001

Tel: +61 7 3854 6200
Fax: +61 7 3854 6500
wsp.com

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	NAME	DATE	SIGNATURE
Prepared by:	Olivia Henderson; Ashlyn Daly	02/12/2019	Ashlyn Daly
Reviewed by:	Brad Simmons Phil Schulz	02/12/2019	
Approved by:	Stephen Barnett	02/12/2019	

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ACRONYMS

6:2 FtS	6:2 Fluorotelomer sulfonate
AFFF	Aqueous Film Forming Foam
ANZECC	Australian and New Zealand Environment Conservation Council
ARMCANZ	Agriculture and Resource Management Council of Australia and New Zealand
ATSDR	Agency for Toxic Substances and Disease Registry
AVN	Aviation
BAF	Bioaccumulation Factor
BW	Body Weight
COPC	Chemicals of Potential Concern
CRC CARE	Cooperative Research Centre for Contamination Assessment and Remediation of the Environment
CSM	Conceptual Site Model
CSR	Contaminated Sites Register
DEHP	Department of Environment and Heritage Protection
DES	Department of Environment and Science
DILGP	Department of Infrastructure, Local Government and Planning
DIWA	Directory of Important Wetlands
DNRM	Department of Natural Resources and Mines
DoEE	Department of Environment and Energy
DoH	Department of Health
DSI	Detailed Site Investigation
DSITI	Department of Science, Information, Technology and Innovation
DW	Dry Weight
EILs	Ecological Investigation Levels
EC	Environment Canada
EPBC	Environment Protection and Biodiversity Conservation
EPC	Exposure Point Concentration
EPP	Environmental Protection (Water) Policy
ERA	Ecological Risk Assessment
ESP	Ecological Service Professionals Pty Ltd

FEQG	Federal Environmental Quality Guidelines
FHA	Fish Habitat Area
FSANZ	Food Standards Australia New Zealand
GBRMP	Great Barrier Reef Marine Park
GSE	Ground Support Equipment
HBW	Handbook of the Birds of the World
HEPA	Heads of EPAs Australia and New Zealand
HHRA	Human Health Risk Assessment
HI	Hazard Index
HQ	Hazard Quotient
HR	Home Range
IA	Investigation Area
IUCN	International Union for Conservation of Nature
LC	Lethal Concentration
LD	Lethal Dose
LOAEL	Lowest Observed Adverse Effect Level
LOR	Limit of Reporting
mAHD	Metres Australian Height Datum
mBGL	Metres Below Ground Level
mg/kg	Milligrams per kilogram
MNES	Matters of National Environmental Significance
MSES	Matters of State Environmental Significance
NA	Not Applicable
NEMP	National Environmental Management Plan
NEPC	National Environment Protection Council
NEPM	National Environment Protection Measure
NOAEL	No Observed Adverse Effect Level
NPRSR	Department of National Parks, Recreation, Sport and Racing
OECD	Organisation for Economic Cooperation and Development
OLA	Ordnance Loading Apron
PFAS	Per- and polyfluoroalkyl substances
PFBS	Perfluorobutane sulfonic acid

PFDA	Perfluorodecanoic acid
PFDS	Perfluorodecane sulfonic acid
PFHxA	Perfluorohexanoic acid
PFHxS	Perfluorohexane sulfonic acid
PFNA	Perfluorononanoic acid
PFOA	Perfluorooctanoic Acid
PFOS	Perfluorooctane Sulfonate (alternative name Perfluorooctane sulfonic acid)
PFPeA	Perfluoropentanoic acid
PFPeS	Perfluoropentane sulfonic acid
PMST	Protected Matters Search Tool
RAAF	Royal Australian Air Force
ROC	Receptor of Concern
SAQP	Sampling Analysis and Quality Plan
SPP	State Planning Policy
SQN	Squadron
SSD	Species Sensitivity Distribution
SWL	Standing Water Level
TA	Technical Advisor
TBA	To Be Advised
TCC	Townsville City Council
TDS	Total Dissolved Solids
TRV	Toxicity Reference Value
UCL	Upper Confidence Limit
UF	Uncertainty Factor
US EPA	United States Environmental Protection Agency
WTP	Water Treatment Plant
WW	Wet Weight

GLOSSARY OF TERMS

TERM	DEFINITION
Amphibian	A class of animals that live both on land and in water, comprising cold-blooded vertebrates including frogs, toads and salamanders.
Aquatic	Relating to water.
Aquifer	A geological formation capable of conducting and transmitting water.
Arboreal	Animals which live or spend majority of their time in trees.
Avian	Relating to birds.
Background sample	A sample collected from a location deemed to be representative of natural conditions, exclusive of potential anthropogenic (man-made) contamination sources or activities.
Benthic	Relating to or occurring at the lowest level of a body of water; it includes the sediment surface.
Bioaccumulation	The accumulation of substances in an organism at a rate faster than it can be excreted by that organism.
Biodegradation	The process by which organic substances are decomposed by micro-organisms into simpler substances such as water, carbon dioxide and ammonia.
Biomagnification	The increase in concentration of a substance within a food chain as it moves from one trophic level to the next.
Biota	The animal and plant life of a particular region.
Catchment	The area from which a surface watercourse or a groundwater system derives its water.
Direct toxicity	The hazardous potential of a substance based on its interaction with an organism by directly altering metabolic processes or molecular structures.
Ecological receptor	An animal, plant, or ecosystem that may be detrimentally affected by exposure to PFAS.
Exposure pathway	The pathway a contaminant takes from its source via a medium (air, soil, surface water, groundwater) to a receptor which represents a potential hazard to that receptor.
Exposure point concentration	A conservative estimate of the concentration of a substance (PFAS in the context of this ERA) available in the environment (e.g., soil, sediment and water) to which receptors can be exposed.
Food chain	A linear sequence of organisms through which energy and nutrients pass as one organism eats another.
Food web	A natural inter-connection of food chains in an ecological community, depicting organisms related by predator-prey and consumer-resource interactions.
Herbivorous	Feeding on plants.
Higher order species	A taxonomic rank used to classify organisms, considered to be complex organisms, for example mammals, birds.

TERM	DEFINITION
Invertebrate	An animal without a backbone or spinal column, such as insects.
Invertivorous	Feeding on invertebrates.
Investigation Area	RAAF Base Townsville and surrounding areas defined on Figure 1, Appendix A.
LOAEL	Lowest observed adverse effect level – the lowest level at which there was an observed adverse effect in people or animals.
Lower order species	A taxonomic rank used to classify organisms, considered to be simple organisms, for example plants, invertebrates.
Media/medium	The substance in which an organism lives.
NOAEL	No observed adverse effect level – the highest level at which there was not an observed adverse effect in people or animals.
Omnivorous	Feeding on food of both plant and animal origin.
Point of exposure	The place where an organism can come into contact with a substance in the environment.
Precursor	A substance that participates in a chemical reaction from which PFOS and PFOA may be formed.
Risk assessment	A systematic process of evaluating the potential risk that may be posed by a hazardous substance (PFAS in the context of this ERA) to a receptor in a system.
Soluble	Susceptible to being dissolved in a liquid, especially water.
Source	A potentially hazardous substance that may be released to the environment (PFAS in the context of this ERA).
Terrestrial	Living or growing on land rather than in water or air.
Trophic level	A group of organisms within an ecosystem that occupy the same level of a food chain, e.g. producers, primary consumers, secondary consumers, predators.
TRV	Toxicity reference value is the exposure concentration or dose of a contaminant (PFAS in the context of this ERA) that is not expected to cause an unacceptable level of effect in a receptor of concern.
UF	Uncertainty Factor – a conservative tool to deal with uncertainty in establishing exposure limits. Typically, UFs are applied for the following three elements: — laboratory to field extrapolation — acute to chronic toxicity extrapolation; and — interspecies extrapolation.
Vertebrate	An animal that has a backbone or spinal column, including mammals, reptiles, birds, amphibians, fish.
Volatility	Tendency of a substance to evaporate at normal temperatures.

EXECUTIVE SUMMARY

BACKGROUND

WSP Australia Pty Ltd (WSP) was commissioned by the Department of Defence (Defence) under the Defence per- and poly-fluoroalkyl substances (PFAS) Panel to conduct an Ecological Risk Assessment (ERA). The ERA was undertaken to quantitatively assess the risk to ecological health resulting from potential environmental exposure to PFAS, contained in legacy Aqueous Film Forming Foams (AFFF), used at the Royal Australian Air Force (RAAF) Base Townsville (herein referred to as 'the Base'). The Base is located on Ingham Road, Garbutt, Queensland 4180.

AFFF were stored and used by Defence at the Base for fire-fighting purposes, including routine testing and emergency fire-fighting response practice drills, from approximately the 1970s to 2004. AFFF containing PFOS and PFOA as active ingredients was phased out in approximately 2004 and replaced by another product (Ansulite).

WSP completed a Detailed Site Investigation (DSI) (WSP 2018a) of the Base and surrounding off-Base areas, including the Townsville Town Common Conservation Park (the Town Common) and the suburbs of Garbutt, Rose Bay, Belgian Gardens and Pallarenda (the 'Investigation Area') between April 2017 and February 2018. This report was publicly released in May 2018 by the Department of Defence and presented at a Community-Walk-In-Session.

The ERA also incorporates environmental analytical results collected across the Investigation Area following the rainfall events that occurred across the catchments in post-March 2018. This dataset was presented in the Seasonal Monitoring Report 1 (WSP 2018b).

The ERA also includes aquatic and semi-terrestrial biota analytical results from investigations conducted across the Investigation Area and Cleveland Bay between July 2017 and March 2018. The complete dataset which comprises environmental, aquatic and semi-terrestrial biota results, including the supporting technical reports prepared by those engaged by WSP, to collect the samples ethically, are appended to this report.

The approach to assessing potential risks to the identified ecological receptors within the Investigation Area comprised of two steps:

1. Potential risks to lower order species (i.e. plants, terrestrial/aquatic invertebrates and fish) were assessed by comparing available data to a screening benchmark (criteria) (i.e. the evaluation of direct toxicity); and
2. Potential risks to identified higher order species (i.e. predatory birds, mammals and reptiles) within the Investigation area, were evaluated via quantitative food web modelling (i.e. the evaluation of indirect exposure risk).

This ERA has undergone a rigorous technical review process including:

- an independent Technical Advisor (TA) who is accredited by the Queensland Department of Environment and Science (DES) as a Contaminated Land Auditor (CLA); and
- the Technical Working Group established by the Queensland Government Interdepartmental Committee for Fluorinated Fire Fighting Foam which draws together expertise from the Queensland State Government including Queensland Health and DES.

OBJECTIVES

The purpose of the ERA was to consider potential risks to ecological receptors from direct exposure to PFAS in environmental media, as well as indirect exposure that may occur through dietary intakes of PFAS in various organisms, forming part of the food chain.

The objectives of the ERA are to:

- assess, quantitatively and qualitatively, potential ecological health risks to ecological receptors within the Investigation Area that may be inadvertently exposed (via direct contact), to PFAS impacted environmental media (i.e. soil, groundwater, surface water and sediment) from the Base; and
- assess quantitatively, the potential for risks to higher order species from the transfer of PFAS, from lower order, to higher order species within the terrestrial/semi-terrestrial and aquatic food webs.

FIELD INVESTIGATION FINDINGS

Environmental samples (i.e. soil, groundwater, surface water and sediment), aquatic biota samples (i.e. fish, crustaceans, plants), as well as semi-terrestrial biota samples (i.e. reptiles and amphibians) collected in the field, underwent an initial screening process against published relevant criteria for each media investigated.

The purpose of the screening process was to determine if a sampled media returned results that were above the adopted screening criteria. If the concentrations were found to be above the screening criteria, for a particular media, then additional assessment via the ERA was required to assess the ecological risk.

A review of the on-Base soil data was undertaken across different areas including operational areas with a view, that any identified impacts in soil on-Base, may contribute to off-Base ecological impacts. The reported on-Base soil results indicated that PFOS concentrations in soil at several different areas on the Base were above the adopted ecological screening criteria for an industrial/commercial land use and warranted further evaluation in the ERA. Conversely, concentrations of PFOA in soil were not identified above the screening criteria for ecological risks. Hence, PFOA was not considered to warrant further evaluation.

A review of the off-Base soil data collected from surrounding suburbs from the Base including Bohle, Belgian Gardens, Cleveland Bay, Rowes Bay, the Town Common, Garbutt Community and Pallarenda did not identify concentrations of PFOA to be above the ecological screening criteria. The off-Base soil results obtained during the additional wet season sampling (WSP 2018b) (which targeted properties where PFAS-impacted groundwater was reported in the DSI (WSP 2018a)), did identify concentrations of PFOS in soil (from Rowes Bay, Garbutt and Pallarenda) exceeding ecological screening criteria for an industrial/commercial land use and/or residential land use.

PFAS has been detected in groundwater from most of the monitoring wells on the Base. However, the absence of PFAS in isolated monitoring wells suggests that there isn't one continuous PFAS 'plume' beneath the Base, but a series of PFAS 'plumes' related to specific source areas and possibly surface water bodies. Plumes were interpreted to extend to the east and north-east from the south-eastern section of the Base, west and north-west from 5 AVN and north from the northern end of the runway. The highest PFAS concentrations were generally reported from monitoring wells installed at the known source areas; or immediately downgradient of the source areas.

The detection of PFAS in off-Base monitoring wells to the north-west, north, north-east, south-east and east of the Base suggested that groundwater 'plumes' have transported PFAS off-Base in these directions. The DSI concluded that the groundwater impacts are not continuous 'plumes' in the traditional hydrogeological sense but rather, are more likely to occur at distances from the Base, due to surface water PFAS transport, with subsequent infiltration of PFAS impacted water into the underlying aquifer. Evidence of this transport mechanism appears to be occurring in the surface water bodies of the Town Common, Three Mile Creek and Mundy Creek catchments.

PFAS was detected in surface water and sediment on- and off-Base at concentrations above the ecological screening criteria (benchmarks). The results indicate that PFAS is being transported by surface waters from the Base into the Town Common, Louisa Creek, Three Mile Creek and Mundy Creek catchments. At the time of the DSI investigation, there was no surface water flow from the Base. However, a period of higher flow was observed in the dataset collected for the Seasonal Monitoring Report 1 with elevated PFAS concentrations observed discharging from the Base. It appears that PFAS impacted sediments found at a distance from the Base have been transported to those locations bound to the sediments in these high flow events. Results of samples collected up-gradient of the Base indicate a background source of PFAS exists in the upper catchments of Louisa and Peewee Creeks and in the middle reaches of the Bohle River. However, compared with the concentrations recorded in surface waters discharging from the Base, the background up-gradient input of PFAS concentrations to the Investigation Area is considered to be minor.

Four aquatic biota surveys were completed by Ecological Service Professionals Pty Ltd (ESP) with biota sampling and analysis completed in freshwater, estuarine and marine environments, targeting areas with known PFAS impacts within the Investigation Area, and comparative sites outside the Investigation Area. The complete off-Base aquatic biota dataset is provided in Appendix B of the ERA.

During the first survey in July 2017, concentrations of PFOS and PFHxS were highest in biota samples collected from the Bohle River and Town Common, estuarine systems, generally within fish species, particularly the detritivores (i.e. consume detritus and organic matter) and consumers (i.e. fish that eat other organisms including other fish). Comparative site locations that were sampled within 10 km of the mouth of the Bohle River indicated that the elevated concentrations (i.e. exceeding adopted screening criteria) detected within the Bohle River (located within the Investigation Area) do not extend to this extent (only two biota samples exceeded screening criteria).

Concentrations of PFOS and PFHxS were generally reported at higher concentrations within whole and liver samples compared to fish flesh, and in whole crustaceans compared with flesh alone. It was detected amongst all trophic levels in the Town Common and the majority of trophic levels in Bohle River. Concentrations increased in higher trophic levels. However, high concentrations were also observed in fish detritivores. The first survey did not include large predatory fish. However, the presence within species such as mullet (a food source for predatory species) indicates PFOS and PFHxS is available to larger predatory species. Subsequent surveys which did include large predatory species found that the majority of liver samples contained detectable PFOS + PFHxS concentrations and the marine survey generally found the highest concentrations within predatory species as discussed below.

The second survey conducted in November/December 2017 was undertaken within three estuarine impact sites within the Investigation Area and two comparative estuarine sites outside the Investigation Area. PFOS and PFHxS were again the most widespread PFAS compounds detected and within the impact sites these PFAS compounds were detected in 76% of fish or crustacean biota samples. PFAS was not detected within any plant samples. At the comparative sites, only 8% of all biota samples reported detectable concentrations of PFOS and/or PFHxS.

The third aquatic survey comprised analysis of marine biota samples collected from south-west of Magnetic Island, Rowes Bay, Althaus Creek and Bohle River in March 2018. Two sites (Bohle River mouth and Rowes Bay) were located within the Investigation Area and three sites represented comparative sites outside the Investigation Area (Magnetic Island and Althaus Creek).

PFOS and PFHxS were the most widespread PFAS compounds detected (detected in 46% of all samples, 53% of samples from impact sites, and 36% of samples from comparative sites); and Bohle River reported most of the elevated PFOS and PFHxS. Of the impact sites, the highest concentrations were detected in liver samples of apex predators (barred queenfish or barramundi) from the Bohle River mouth. A consumer species (blue catfish) from Rowes Bay also reported one of the highest concentrations.

From samples collected at the comparative sites, the highest concentration of PFOS and PFHxS was reported within a detritivore liver sample of a diamond scale mullet, collected from Althaus Creek mouth. Mature mullet are known to migrate long distances and so it is possible that exposure may be a result of time spent within other environments more akin to the impact sites located within the Investigation Area.

A semi-terrestrial fauna survey and sampling program was undertaken in February 2018. A total of 84 semi-terrestrial fauna biota samples (comprising a mixture of reptiles and amphibians) were collected from four separate sampling locations, three within the Investigation Area and one comparative site, outside the Investigation Area. Concentrations of PFOS and PFHxS were detected in semi-terrestrial fauna species sampled at each of the four locations. Considering all semi-terrestrial fauna biota samples, 93% of those collected within the Investigation Area contained a PFOS and PFHxS concentration exceeding the adopted ecological screening criteria. The off-Base semi-terrestrial biota dataset is provided in Appendix B of the ERA.

Within amphibians, the cane toad consistently reported higher average concentrations of PFOS and PFHxS at each sampling location, and amphibians from the Town Common reported the highest average PFOS and PFHxS concentrations followed by the wetland in Rowes Bay, Louisa Creek Wetland and Alligator Creek. The combined average of PFOS and PFHxS concentration reported in amphibians from the Investigation Area was 67 µg/kg and therefore exceeded the adopted ecological screening criteria.

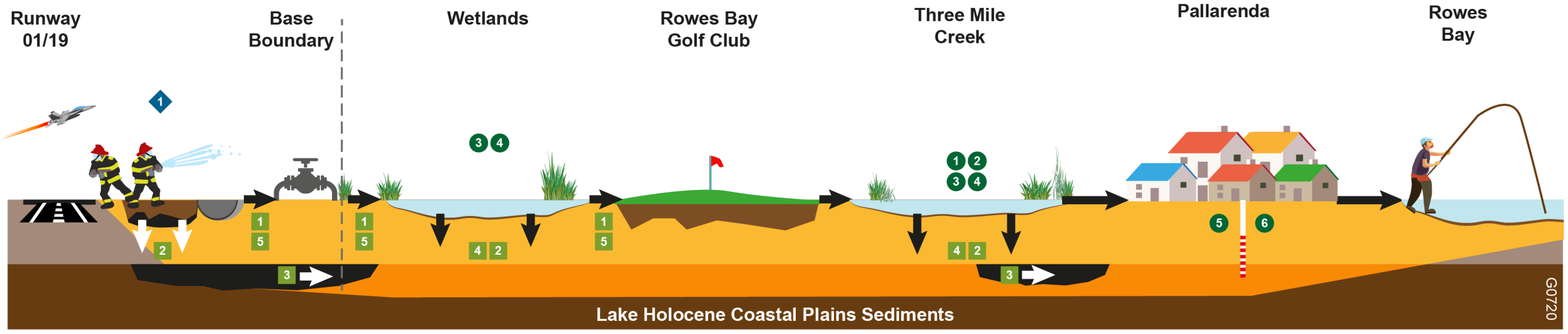
Within reptiles, the freshwater snake reported higher average concentrations of PFOS and PFHxS compared to the Canns Longnecked turtle, and the highest concentrations in biota samples by far were reported in the Town Common, followed by the wetland in Rowes Bay and Louisa Creek Wetland. Concentrations of PFOS and PFHxS in samples of freshwater snake from the Town Common were generally an order of magnitude higher than the Canns Longnecked turtle. Samples from the comparative site Alligator Creek did not contain detectable concentrations of PFOS and PFHxS (based on four freshwater snake samples). The combined average PFOS and PFHxS concentration reported in reptiles from the Investigation Area was 1,152 µg/kg and therefore exceeded the adopted ecological screening criteria.

The assessment of PFAS concentrations within two trophic levels (i.e. secondary consumers (amphibians) and tertiary consumers (reptiles)) that belong to the semi-terrestrial food web, indicated that bioaccumulation and hence, biomagnification was occurring within the food chain and more specifically, the tertiary consumers sampled as part of the investigation.

CONCEPTUAL SITE MODEL

The CSM has been presented in three parts, representing the three primary receiving surface water catchments in the Investigation Area (Louisa Creek/Town Common/Bohle River; Three Mile Creek; Mundy Creek). Summary of the linkages between identified sources, exposure pathways and sensitive receptors for the three catchments is in a graphical representation provided in Figures ES.1, ES.2 and ES.3 overleaf.

Three Mile Creek Catchment



KEY

- Inferred Groundwater Flow
- Surface Water Runoff / Migration
- Groundwater Impact and Migration
- Groundwater Table
- Subsurface Migration

SOURCES

1. Former fire training ground NQ0105

PATHWAYS

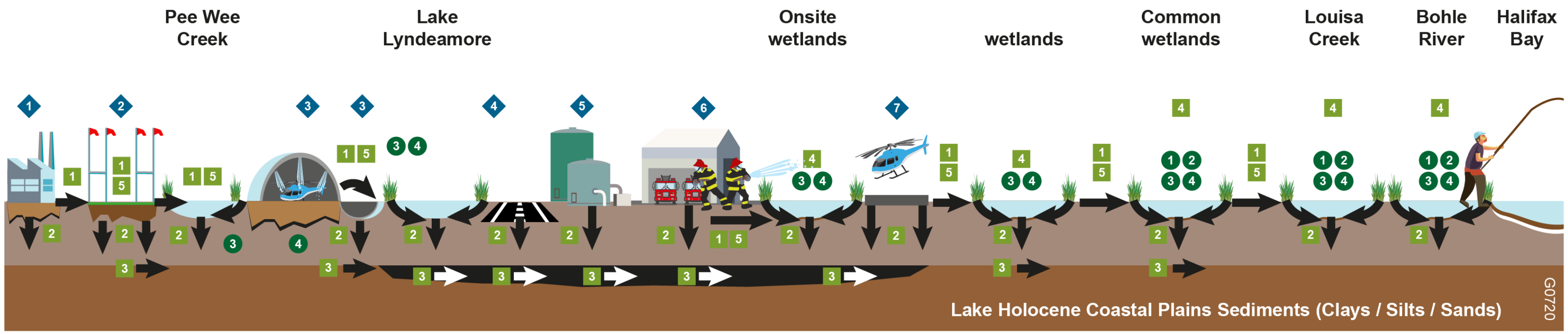
1. Surface water runoff
2. Surface water infiltration
3. Groundwater migration
4. Biomagnification
5. Sediment migration

POTENTIALLY COMPLETED PATHWAYS

1. Human direct contact (surface water)
2. Human ingestion of aquatic organisms
3. Aquatic ecosystems - direct contact (surface water and sediment)
4. Terrestrial and aquatic predators
5. Human ingestion/ inhalation of groundwater
6. Human ingestion of stock or produce grown with groundwater

Figure ES.1 Conceptual Site Model for the Three Mile Creek catchment

Louisa Creek / Common Catchment



KEY

- Inferred Groundwater Flow
- Surface Water Runoff / Migration
- Groundwater Impact and Migration
- Groundwater Table
- Subsurface Migration

SOURCES

1. Potential unidentified off-Base source
2. Ingham Road sports field
3. 5AVN hangers and washplant
4. Runway 13/31
5. Fuel farm 2 NQ0099
6. Fire station NQ 0055
7. Pad Brahman

PATHWAYS

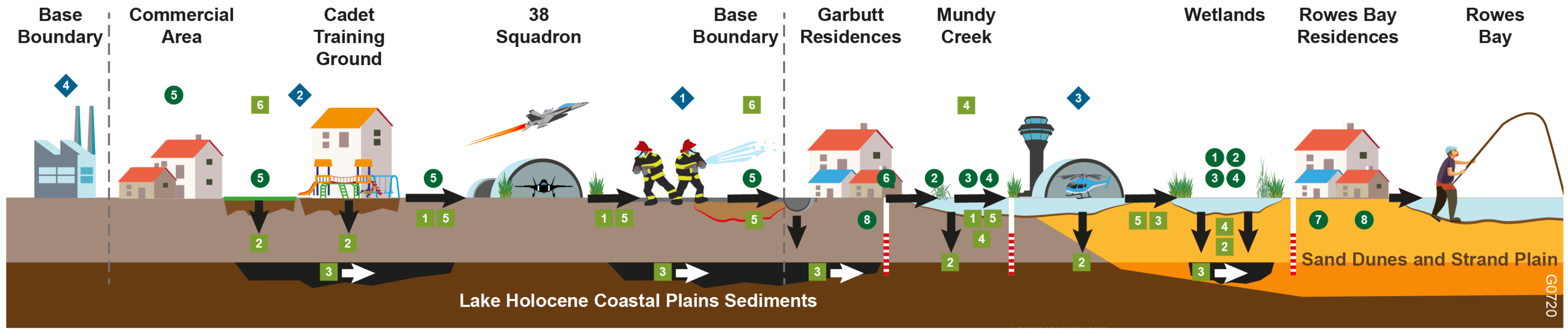
1. Surface water runoff
2. Surface water infiltration
3. Groundwater migration
4. Biomagnification
5. Sediment migration

POTENTIALLY COMPLETED PATHWAYS

1. Human direct contact (Surface water)
2. Human ingestion of aquatic organisms
3. Aquatic ecosystems direct contact (Surface water and sediment)
4. Terrestrial and aquatic predators

Figure ES.2 Conceptual Site Model for the Louisa Creek/Town Common/Bohle River catchment

Mundy Creek Catchment



KEY

- Inferred Groundwater Flow
- Surface Water Runoff / Migration
- Groundwater Impact and Migration
- Groundwater Table
- Subsurface Migration

SOURCES

1. Former fire training ground NQ0054
2. Former cadet training ground
3. Potential former fire training ground
4. Potential unidentified off-Base source

PATHWAYS

1. Surface water runoff
2. Surface water infiltration
3. Groundwater migration
4. Biomagnification
5. Sediment migration
6. Wind erosion - aerial transport of dust particles

POTENTIALLY COMPLETED PATHWAYS

1. Human direct contact (surface water)
2. Human ingestion of aquatic organisms
3. Aquatic ecosystems - direct contact (wind/sediment)
4. Terrestrial and aquatic predators
5. Human inhalation and direct contact (soil/dust)
6. Human ingestion/inhalation of groundwater aerosols
7. Human ingestion/ inhalation of groundwater
8. Human ingestion of stock or produce grown with groundwater

Figure ES.3 Conceptual Site Model for the Mundy Creek catchment

ADOPTED TOXICITY REFERENCE VALUES (TRVs)

Toxicity Reference Values (TRVs) for PFAS based on dose (mass of chemical per unit of body weight) were identified for birds, mammals and reptiles based on the results of a literature search and review of other available sources. The TRVs were used in the risk characterisation step to calculate risks for the receptors based on the dose estimates calculated from the food web modelling. TRVs for PFOS and PFOA were adopted as more reliable dietary dose-response studies were available for these particular PFAS compounds. Consideration of other PFAS compounds reported within the various media (such as PFHxS) was also given in the context of their potential toxicity to ecological receptors, there is however relatively limited information available. Therefore, while a TRV for PFHxS has not been adopted in the ERA, it is being evaluated in the Human Health Risk Assessment (HHRA) as an additive with PFOS.

In developing TRVs for ecological receptors, typically a No Observed Adverse Effect Level (NOAEL) and Lowest Observed Adverse Effect Level (LOAEL) can be selected for individual receptor species or receptor groups using several critical toxicity studies. The NOAEL and LOAEL are chronic toxicity (i.e. as a result of long-term exposure to a chemical) values that have been used to determine the concentration of PFAS that the ecosystem can be exposed to without adverse effects or with adverse effects of a certain magnitude. The resulting TRVs are based on the selected NOAEL and LOAEL concentrations.

A summary of the TRVs is provided in Table ES.1.

Table ES.1 Summary of adopted TRVs for birds, reptiles and mammals

SPECIES AND ANALYTE	TRV (mg/kg BW/DAY)		TOXICITY ENDPOINT
	NOAEL	LOAEL	
Birds and Reptiles			
PFOS	0.077	0.77	Reproductive endpoints (i.e. reduction in fertility, hatchability and offspring survival, and growth of offspring).
PFOA	0.077	0.77	In the absence of TRVs for PFOA, PFOS has been used as a surrogate.
Mammals			
PFOS	0.1	0.4	Reproductive endpoints in singular and multi-generational studies, including maternal weight gain, litter size and weight, delayed reflexes and physical development.
PFOA	6.2	7.6	Reproduction and developmental endpoints, including reduction in weight gain, delayed physical development, reduced motor coordination.

EXPOSURE ASSESSMENT

For a receptor to be exposed to a chemical a complete exposure pathway must exist. An exposure pathway describes the path a chemical takes from the source to the receptor. For an exposure pathway to be deemed complete, a source, transport mechanism, point of contact; and an exposure route (i.e. ingestion of plants, soil or biota) at the point of exposure **must** be present. If all elements are present in a system, the source-pathway-receptor linkage is considered complete and a receptor is potentially at risk. If one of the components is absent, then the source-pathway-receptor linkage is broken. Hence, no risk is considered to be present.

The exposure assessment completed as part of the ERA identified the following incomplete and complete exposure pathways:

INCOMPLETE EXPOSURE PATHWAYS

- Dermal uptake of PFAS from environmental media. Dermal uptake is a minor pathway for PFAS exposure based on our current understanding of the compounds' ability to cross into and through dermal membranes.
- Direct contact with groundwater within the Investigation Area has not been considered for the ERA as direct sampling of surface water has been undertaken in the various surface water bodies which are connected to the site. It is understood there is potential for groundwater seeps to occur in areas within the Investigation Area (i.e. lower reaches of Mundy Creek). However, this is likely to occur following heavy rain events. A direct assessment of the potential toxicity associated with the consumption/ingestion of surface water PFAS impacts is considered to be a more appropriate approach, as the potential exposure to groundwater is likely to be intermittent.

Of note, the ingestion of PFAS in groundwater was not evaluated as a separate exposure scenario. It has been assumed that surface water samples including samples collected in areas where groundwater is known to discharge to surface waters will provide a better representation of potential exposures as a result of water ingestion.

COMPLETE EXPOSURE PATHWAYS

TERRESTRIAL AND SEMI-TERRESTRIAL ORGANISMS:

Exposure routes considered likely to result in complete pathways for terrestrial and semi-terrestrial organisms are as follows:

- incidental ingestion of PFAS adhered to soil and sediment (i.e. animals – invertebrates and vertebrates)
- uptake and bioaccumulation of PFAS from soil moisture (i.e. plants)
- ingestion of dissolved PFAS in water sources (i.e. animals drinking from and/or inhabiting water sources)
- ingestion of PFAS that has bioaccumulated in food sources (i.e. animals – invertebrates and vertebrates).

Of note, the uptake and bioaccumulation of PFAS from the environment into plants on-Base was assessed based on a comparison to soil data only and was inferred to be complete. Off-Base impacts have been assessed via direct measurement of PFAS in plant samples (samphire, mangrove, seagrass) which indicated an incomplete exposure pathway. This exposure pathway wasn't included in food web modelling.

AQUATIC ORGANISMS (ESTUARINE AND FRESHWATER):

Exposure routes considered likely to result in complete pathways for aquatic organisms are as follows:

- incidental ingestion of PFAS adhered to sediment (i.e. animals – invertebrates and vertebrates)
- uptake and bioaccumulation of PFAS from sediment pore water and/or surface water (all aquatic organisms); and
- ingestion of PFAS that has bioaccumulated in food sources (i.e. animals – invertebrate sand vertebrates).

The uptake and bioaccumulation of PFAS into aquatic plants and algae has been assessed via direct measurement of PFAS in plant samples. Theoretical modelling of bioaccumulation into aquatic plants was not considered appropriate given the significant variability in potential exposure concentrations in surface water.

CONCLUSIONS

LOWER ORDER SPECIES

The potential ecological risk to lower order species (i.e. plants, terrestrial invertebrates, aquatic invertebrates and fish) was assessed via the direct toxicity approach, as these receptors are the most highly exposed to impacts within the environment (i.e. direct contact to PFAS adhered to soil, sediment and/or dissolved in surface water systems). A summary of the potential for impact and for direct toxicity to occur to lower order species as a result of exposure to PFAS in soil, sediment and/or surface water is summarised below in Table ES.2. The potential for direct toxic impact was classified as follows:

- Possible: Average and/or maximum PFOS or PFOA concentrations (for a particular media) exceeded the screening benchmark criteria.
- Unlikely: Average and/or maximum PFOS or PFOA concentrations (for a particular media) were below the screening benchmark criteria.

Table ES.2 Summary of ecological risks – lower order species

SEASON	ANALYTE	MEDIA	AREA	SPECIES GROUP	SCREENING ASSESSMENT OUTCOME	POTENTIAL FOR DIRECT TOXIC IMPACT
Dry	PFOS	Soil	on-Base	Terrestrial/semi-terrestrial plants and invertebrates	Average and/or maximum concentrations were above screening benchmark criteria.	Possible
		Surface water		Aquatic plants, invertebrates and fish		Possible
		Sediment				Possible
Dry	PFOS	Soil	off-Base	Terrestrial/semi-terrestrial plants and invertebrates	Average and maximum concentrations were above screening benchmark criteria.	Possible
		Surface water		Aquatic plants, invertebrates and fish	Average and/or maximum concentrations were above screening benchmark criteria.	Possible
		Sediment			Average and/or maximum concentrations were above screening benchmark criteria.	Possible
		Aquatic biota tissue		Mammals and birds that consume aquatic biota	Above the criteria for birds and/or mammals that consume aquatic biota.	Possible
Wet	PFOS	Soil	on-Base	Terrestrial/semi-terrestrial plants and invertebrates	Average was below the screening benchmark criteria but the maximum was above. *NB: only x4 samples collected during the wet season.*	Possible. However, small dataset in which to evaluate direct toxic impacts.
		Surface water		Aquatic plants, invertebrates and fish	Average and/or maximum concentrations were above screening benchmark criteria.	Possible
		Sediment				Possible
Wet	PFOS	Soil	off-base	Terrestrial/semi-terrestrial plants and invertebrates	No data to assess direct toxic impacts.	
		Surface water		Aquatic plants, invertebrates and fish	Average and/or maximum concentrations were above screening benchmark criteria.	Possible
		Sediment				Possible

SEASON	ANALYTE	MEDIA	AREA	SPECIES GROUP	SCREENING ASSESSMENT OUTCOME	POTENTIAL FOR DIRECT TOXIC IMPACT
Dry	PFOA	Soil	on-Base	Terrestrial/semi-terrestrial plants and invertebrates	Average and maximum concentrations were below screening benchmark criteria.	Unlikely
		Surface water		Aquatic plants, invertebrates and fish	Average and maximum concentrations were below screening benchmark criteria.	Unlikely
		Sediment				Unlikely
Dry	PFOA	Soil	off-Base	Terrestrial/semi-terrestrial plants and invertebrates	Average and maximum concentrations were below screening benchmark criteria.	Unlikely
		Surface water		Aquatic plants, invertebrates and fish	Average and maximum concentrations were below screening benchmark criteria.	Unlikely
		Sediment				Unlikely
		Aquatic biota tissue		Mammals and birds that consume aquatic biota	PFOA concentrations were either below the laboratory LOR or below screening benchmark criteria.	Unlikely
Wet	PFOA	Soil	on-Base	Terrestrial/semi-terrestrial plants and invertebrates	Average and maximum concentrations were below screening benchmark criteria.	Unlikely
		Surface water/ sediment		Aquatic plants, invertebrates and fish	Average and maximum concentrations were below screening benchmark criteria.	Unlikely
		Sediment				Unlikely
Wet	PFOA	Soil	off-Base	Terrestrial/semi-terrestrial plants and invertebrates	No data to assess direct toxic impacts.	
		Surface water/ sediment		Aquatic plants, invertebrates and fish	Average and maximum concentrations were below screening benchmark criteria.	Unlikely
		Sediment				Unlikely

HIGHER ORDER SPECIES

Potential risks to higher order species were evaluated via a combination of direct toxicity impacts for available biota tissue data. Quantitative food web modelling was then undertaken for the selected bird, reptile and mammal species, for both terrestrial/semi-terrestrial and aquatic food webs, to determine a total PFOS intake for each receptor (based on dietary consumption). The modelled intakes were then compared against the relevant TRVs for birds/reptiles and mammals. The following ecological risks to higher order species have been quantitatively predicted via food web modelling and are summarised below in Table ES.3. Of note, potential risks were only quantified for PFOS as concentrations of PFOA across the various media were below the screening benchmark criteria and hence, PFOA was not considered to warrant further quantitative assessment.

The potential risk to higher order species was classified as follows:

- Potential for exposure to bioaccumulated PFOS through the food web: the modelled PFOS intake for a particular trophic level was above the LOAEL and/or the NOAEL.
- Low and acceptable: the modelled PFOS intake for a particular trophic level was below both the LOAEL and the NOAEL.

Table ES.3 Summary of ecological risks – higher order species

TROPHIC LEVEL	DRY SEASON – PREDICTED RISK OUTCOME	WET SEASON – PREDICTED RISK OUTCOME
TERRESTRIAL/SEMI-TERRESTRIAL ON-BASE		
Herbivorous Mammals	Potential for exposure to bioaccumulated PFOS through the food web.	Potential for exposure to bioaccumulated PFOS through the food web.
Invertivorous and Omnivorous Mammals	Potential for exposure to bioaccumulated PFOS through the food web.	Potential for exposure to bioaccumulated PFOS through the food web.
Herbivorous Birds	Potential for exposure to bioaccumulated PFOS through the food web.	Potential for exposure to bioaccumulated PFOS through the food web.
Invertivorous and Omnivorous Birds	Potential for exposure to bioaccumulated PFOS through the food web.	Potential for exposure to bioaccumulated PFOS through the food web.
Predatory Mammals	Marginal	Marginal
Predatory Reptiles	Low and acceptable	Low and acceptable
Predatory Birds	Potential for exposure to bioaccumulated PFOS through the food web.	Potential for exposure to bioaccumulated PFOS through the food web.
TERRESTRIAL/SEMI-TERRESTRIAL OFF-BASE		
Herbivorous Mammals	Low and acceptable	Low and acceptable
Invertivorous and Omnivorous Mammals	Low and acceptable	Low and acceptable
Herbivorous Birds	Low and acceptable	Low and acceptable
Invertivorous and Omnivorous Birds	Low and acceptable	Low and acceptable
Predatory Mammals	Low and acceptable	Low and acceptable
Predatory Reptiles	Low and acceptable	Low and acceptable
Predatory Birds	Potential for exposure to bioaccumulated PFOS through the food web.	Potential for exposure to bioaccumulated PFOS through the food web.

TROPHIC LEVEL	DRY SEASON – PREDICTED RISK OUTCOME	WET SEASON – PREDICTED RISK OUTCOME
AQUATIC ON-BASE		
Herbivorous Mammals	Receptor not evaluated for on-Base as no known aquatic environments supporting herbivorous mammals on-Base.	
Invertivorous and Omnivorous Birds	Low and acceptable	Potential for exposure to bioaccumulated PFOS through the food web.
Predatory Birds	Low and acceptable	Low and acceptable
Predatory Reptiles	Low and acceptable	Low and acceptable
Predatory Mammals	Marginal	Potential for exposure to bioaccumulated PFOS through the food web.
AQUATIC OFF-BASE		
Herbivorous Mammals	Low and acceptable	Low and acceptable
Invertivorous and Omnivorous Birds	Low and acceptable	Low and acceptable
Predatory Birds	Low and acceptable	Low and acceptable
Predatory Reptiles	Low and acceptable	Low and acceptable
Predatory Mammals	Low and acceptable	Low and acceptable

In summary, the findings of the ERA have identified that there is a potential for direct toxicity effects to occur to lower order terrestrial/semi-terrestrial and aquatic species (i.e. plants, terrestrial invertebrates, aquatic invertebrates, fish), based on a comparison of the reported soil, surface water, sediment and/or biota tissue concentrations to adopted screening benchmarks.

Further evaluation of potential risks to higher order species was conducted for terrestrial/semi-terrestrial and aquatic receptors via quantitative food web modelling. The results of the quantitative modelling indicated the following:

ON-BASE TERRESTRIAL AND SEMI-TERRESTRIAL RECEPTORS

- Predatory mammals – low and acceptable ecological risk.
- Predatory reptiles – low and acceptable ecological risk.
- Herbivorous mammals – potential for exposure to bioaccumulated PFOS through the food web.
- Invertivorous and omnivorous mammals – potential for exposure to bioaccumulated PFOS through the food web.
- Herbivorous birds – potential for exposure to bioaccumulated PFOS through the food web.
- Invertivorous and omnivorous birds – potential for exposure to bioaccumulated PFOS through the food web.
- Predatory birds – potential for exposure to bioaccumulated PFOS through the food web.

ON-BASE AQUATIC RECEPTORS

- Predatory birds – low and acceptable ecological risk.
- Predatory reptiles – low and acceptable ecological risk.
- Invertivorous and omnivorous birds – potential for exposure to bioaccumulated PFOS through the food web.
- Predatory mammals – potential for exposure to bioaccumulated PFOS through the food web.

OFF-BASE TERRESTRIAL AND SEMI-TERRESTRIAL RECEPTORS

- Herbivorous mammals – low and acceptable ecological risk.
- Invertivorous and omnivorous mammals – low and acceptable ecological risk.
- Herbivorous birds – low and acceptable ecological risk.
- Invertivorous and omnivorous birds – low and acceptable ecological risk.
- Predatory mammals – low and acceptable ecological risk.
- Predatory reptiles – low and acceptable ecological risk.
- Predatory birds – potential for exposure to bioaccumulated PFOS through the food web.

OFF-BASE AQUATIC RECEPTORS

- Herbivorous mammals – low and acceptable ecological risk.
- Invertivorous and omnivorous birds – low and acceptable ecological risk.
- Predatory birds – low and acceptable ecological risk.
- Predatory reptiles – low and acceptable ecological risk.
- Predatory mammals – low and acceptable ecological risk.

ASSUMPTIONS AND LIMITATIONS OF THE ERA

This ERA is based on the following key assumptions, limitations and approach to quantifying ecological risks:

- The outcomes of the ERA are based on current concentrations as measured throughout the DSI (WSP 2018a and 2018b) and during aquatic and semi-terrestrial biota sampling events. Therefore, the ERA cannot evaluate potential risks to ecological receptors as a result of changes in PFAS concentrations in the environment since collection of the DSI data and biota samples. Similarly, the ERA has not considered any cumulative impacts to ecological receptors from historical exposure as this is not considered possible (or plausible) as the concentrations within the various media were not known.
- The assessment of potential ecological risks was based on data obtained during the DSI (WSP 2018a and 2018b), during the semi-terrestrial biota sampling event (WSP 2018d) and ESP's aquatic biota sampling programs between July 2017 and March 2018.
- DSI (WSP 2018a and 2018b) sampling and analysis that targeted both on-Base and off-Base media during the dry and wet season included soil, groundwater, sediment and surface water. Aquatic biota (i.e. finfish, crustaceans, plants and bivalves) samples were collected in the dry season and just prior to the start of the wet season, and semi-terrestrial biota samples were collected just prior to the start of the wet season. Hence, an evaluation for how PFAS concentrations may vary during seasonal changes was not undertaken. Aquatic biota sampling was also limited to seasonal availability of different fish species and accessibility for sampling.
- No site-specific sampling was undertaken for terrestrial invertebrate species (i.e. insects, earthworms etc.). However, earthworm data was utilised from AECOM (2016a) as a substitute.
- The selection of receptors and species in which to sample and/or include within quantitative food web modelling were those which have an affinity with aquatic environments, as it is was assumed that they will have higher exposure to PFAS concentrations present within the environment, and were used to infer or consider potential risks to other trophic levels within only terrestrial environments.
- In the absence of site-specific data for some species/trophic groups including terrestrial invertebrates and herbivorous mammals, the adopted exposure point concentrations were based on available data from other completed Defence investigations, primarily from AECOM (2016a). For terrestrial invertebrates, earthworm data was adopted as a substitute. For herbivorous mammals, rabbit tissue data from AECOM (2016b), was adopted as a substitute.
- In the absence of available wild bird tissue or bird egg data, chicken egg data as reported in AECOM (2016a) was adopted as a representative (substitute) exposure point concentration for quantitative modelling purposes.
- One of the primary uncertainty factors when undertaking food web modelling is the absence of species specific food and water ingestion rates for some Australian species. In the absence of Australian data, it is unclear whether the adopted assumptions would result in an under or over estimation of risks.
- Quantitative food web modelling for higher order species evaluates the potential exposure as a direct result of bioaccumulation of PFAS in the diet of terrestrial/semi-terrestrial and aquatic birds, reptiles and mammals. However, the additional exposure risk associated with biomagnification within higher order species cannot be accounted for or evaluated via food web models.
- The modelling of a receptor's exposure from ingestion of dietary items assumes all items contain PFAS, however it is more likely that not all dietary components would contain PFAS as they are sourced from different areas and seasonal variation may also occur.
- The whole Investigation Area has been assumed to be contaminated with the concentrations adopted at the point of exposure. This does not account for the range of reported concentrations for various media, as well as seasonal variability which appears to be occurring to some degree. This therefore results in conservative estimates of risks to ecological receptors.

- The home range value adopted was based on twice the size of the Investigation Area to account for migratory species which move to areas outside the Investigation Area. Given the extensive migration of some bird species (identified in the Investigation Area), the adopted home range value is considered very conservative and therefore likely results in an overestimation of risks to migratory receptors.
- It has been assumed for modelling purposes that the proportion of available suitable habitat within the Investigation Area is 100%. This is considered to be conservative, as it is more likely the migratory species may move outside of the Investigation Area reducing their potential exposure to PFAS. This may result in conservative estimates of risks to these species, but is considered appropriate in the absence of specific data.
- Potential risks for reptiles considered as tertiary consumers (freshwater snake and Canns Longnecked turtle) was quantified using toxicity reference values for avian species as no toxicity or dose-response information is currently available for reptilian species. Little is also known about how they metabolise PFAS or other emerging chemicals. Hence the evaluation of risks to reptilian species via quantitative food web modelling may not be providing a conservative (or representative) risk estimate.
- Domestic animals (both farm and residential) have not been evaluated as part of the ERA as they are not considered to be exposed in the same way as wild ecological receptors (i.e. they are often fed food from other sources including food scraps and/or packaged pet food). They are likely to primarily drink tap water rather than bore water or surface water. Management measures can also be implemented to prevent exposure including the use of reticulated town water instead of groundwater, and supplementing food supply, so that animals are not eating produce grown in impacted soil, groundwater or surface water.

PFAS MANAGEMENT AREA PLAN

The data obtained from the investigations to date have been utilised as input to the PFAS Management Area Plan (PMAP) for the Base currently under development. The PMAP seeks to provide management plans to mitigate the potential impact to human health and the environment from identified PFAS in the Investigation Area and to mitigate the potential migration of PFAS off-Base. An ongoing monitoring plan is included within the PMAP to identify changes in PFAS impact over time within the Investigation Area.

1 INTRODUCTION

WSP Australia Pty Ltd (WSP) was commissioned by the Department of Defence (Defence) under the Defence per and poly-fluoroalkyl substances (PFAS) Panel to conduct an Ecological Risk Assessment (ERA) to quantitatively assess the risk to the environment resulting from exposure to the historical use of Aqueous Film Forming Foams (AFFF) containing PFAS at the Royal Australian Air Force (RAAF) Base Townsville. Herein referred to as 'the Base', located on Ingham Road, Garbutt, Queensland.

The WSP assessment included the following:

- Review of site history information (and previous assessment reports) to identify potential areas of AFFF use and storage.
- Collection of soil, sediment, surface water, groundwater, aquatic and semi-terrestrial biota samples from areas potentially contaminated by PFAS.
- Comparison of the above sample results to published guidelines (for each media type) for an initial evaluation of potential human health and ecological risk. This information was reported in the Detailed Site Investigation (DSI) Report (WSP, 2018a) and Seasonal Monitoring Report 1 (WSP, 2018b) except for the biota sample results (contained herein) and the Human Health Risk Assessment (HHRA) (WSP, 2018c).
- Where concentrations were reported above the published guideline values, further assessment was required. This document (i.e. the ERA report) documents the evaluation of ecological risk associated with PFAS contamination identified within the Investigation Area for RAAF Base Townsville (refer to Figure 1, Appendix A). An evaluation of human health risk associated with the identified PFAS contamination has been undertaken as part of the HHRA (WSP, 2018c) for the Base.
- This assessment has not addressed potential ecological risks associated with other chemicals.

1.1 BACKGROUND

AFFF were stored and used by Defence at the Base for fire-fighting purposes, including routine testing and emergency fire-fighting response practice drills from approximately the 1970s to 2004. AFFF containing PFAS was phased out in approximately 2004 and replaced by another product (Ansulite).

WSP has undertaken a DSI (WSP, 2018a and 2018b) across the Investigation Area (which incorporates both on-Base and off-Base areas), targeting soil, sediment, surface water, groundwater, aquatic and semi-terrestrial biota. A Queensland Department of Environment and Science (DES) accredited auditor, Phil Sinclair of Coffey, was engaged by Defence as the Technical Advisor (TA); and third party reviewer of technical deliverables for the project.

1.2 OBJECTIVES

The objectives of the ERA are to:

- assess the potential for PFAS contaminants in soil, sediment, surface water, and groundwater to pose adverse effects to ecological receptors which inhabit within the Investigation Area
- assess the potential for risks to higher order wildlife (i.e. piscivorous birds (birds that eat fish), terrestrial, marine and estuarine mammals; and birds of prey) that eat lower order species containing PFAS; and
- assist in guiding the remediation and/or risk management measures to address PFAS contamination within the Investigation Area.

2 ERA FRAMEWORK

In accordance with the United States Environmental Protection Agency (US EPA), PFAS are classified as emerging contaminants. Thus, information regarding the fate, transport and toxicity of PFAS is the subject of ongoing development with new information becoming available on a regular basis. Hence, the ERA has been prepared in cognisance of this; and in consultation with various stakeholders including the Commonwealth, the Queensland Government, Townsville City Council (TCC), Defence, the TA and Traditional custodians.

The ERA has been undertaken in accordance with the following national guidelines:

- National Environment Protection (Assessment of Site Contamination) Amendment Measure 2013' (NEPC 2013). The relevant provision within the NEPM is:
  - Schedule B5 – Guideline on Ecological Risk Assessment.
- Heads of EPAs Australia and New Zealand (HEPA), PFAS National Environmental Management Plan (NEMP), January 2018 (referred to herein as the PFAS NEMP (January 2018).
- Australia and New Zealand Guidance for Fresh and Marine Water Quality. Australian and New Zealand Environment and Conservation Council (ANZECC) and Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ) (ANZECC 2000).
- Commonwealth Environmental Management Guidance on Perfluorooctane Sulfonic Acid (PFOS) and Perfluorooctanoic Acid (PFOA). Draft dated October 2016 and published December 2016. Department of the Environment and Energy.

Where required, additional guidance has also been sourced from international references and referenced within this ERA report. The selection of potential receptors for each trophic level was based on the findings of the following database searches and primary reference sources:

- Department of the Environment and Energy – http://www.environment.gov.au/cgi-bin/sprat/public/sprat.pl
- Australian Museum – https://australianmuseum.net.au/
- Queensland Museum – http://www.qm.qld.gov.au/
- Birdlife Australia – http://birdlife.org.au/
- Birds in Backyards – http://www.birdsinbackyards.net/finder
- Australian Reptile Online Database – http://www.arod.com.au/arod/
- International Union for Conservation of Nature (IUCN) Red List – http://www.iucnredlist.org/
- Handbook of the Birds of the World (HBW) Alive – http://www.hbw.com/
- Queensland Department of Science, Information, Technology and Innovation (DSITI) – Wildlife Online
- Commonwealth Government's – Environment Protection and Biodiversity Conservation (EPBC) Act Protected Matters Search Tool.

The overall approach adopted for the ERA was based on Schedule B5 of the NEPM (NEPC 2013) and is summarised in Figure 2.1.

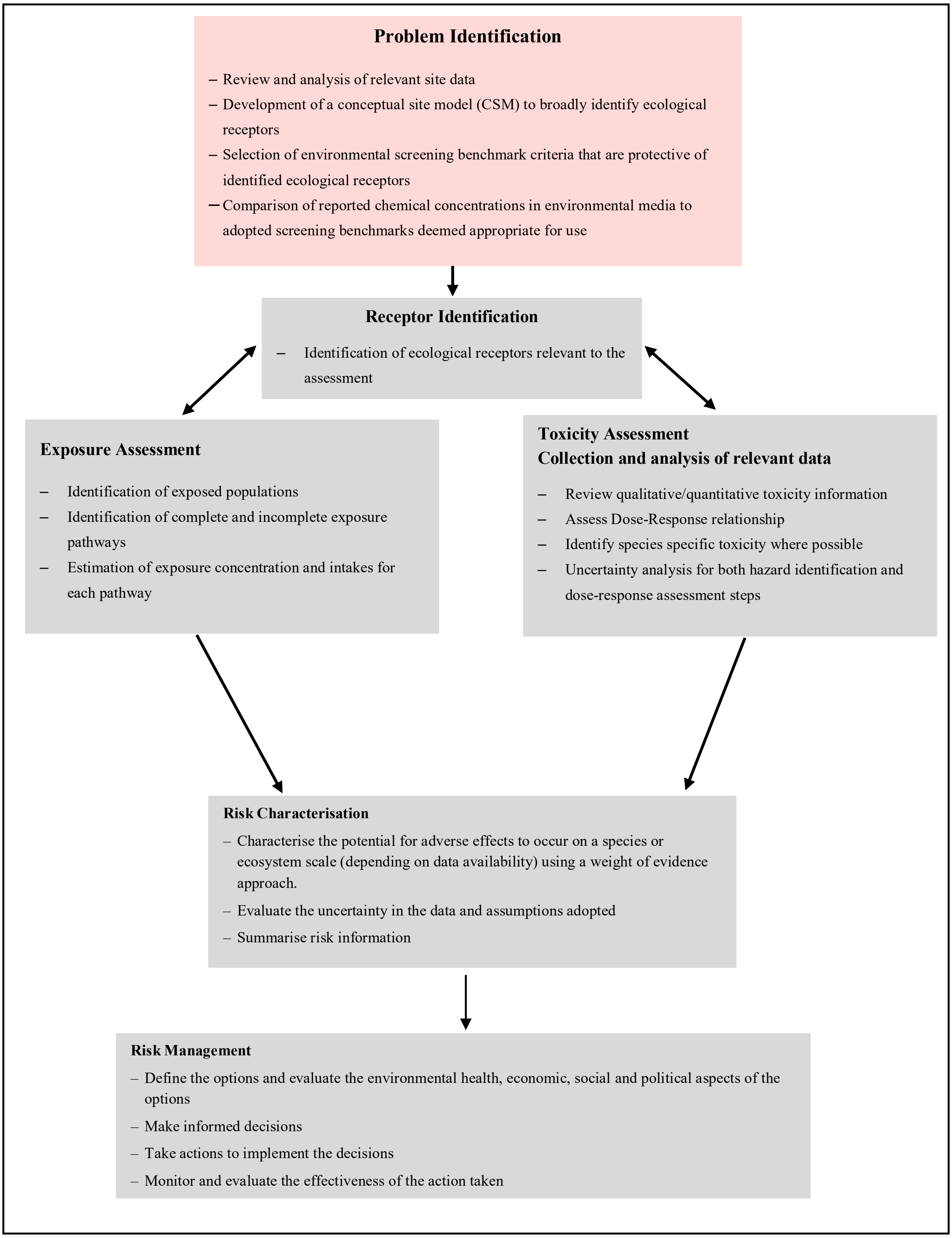


Figure 2.1 Ecological Risk Assessment framework

2.1 AVAILABLE INFORMATION

The ERA has relied on information collected as part of the DSI program (WSP, 2018a and 2018b) as well as data obtained for aquatic biota sampling by Ecological Service Professionals Pty Ltd (ESP).

The information and data that has formed the basis of the ERA includes the following reports which document the collection and analysis of environmental media inclusive of biota, as used in this risk assessment:

- AECOM (2015) *Town Common Rehabilitation and Maintenance Management, Mt St John WWTP.*
- ESP (2018a), RAAF Base Townsville – PFAS Investigation Aquatic Biota Sampling and Analysis, July 2018. Prepared by Ecological Service Professionals Pty Ltd.
- ESP (2018b), RAAF Base Townsville – PFAS Investigation Estuarine Biota Sampling and Analysis, July 2018. Prepared by Ecological Service Professionals Pty Ltd.
- ESP (2018c), RAAF Base Townsville – PFAS Investigation Marine Biota Sampling and Analysis, August 2018. Prepared by Ecological Service Professionals Pty Ltd.
- WSP (2018a), RAAF Base Townsville Detailed Site Investigation. WSP Australia Pty Ltd.
  - PFAS Volume 1: Main Report, 02 May 2018.
  - PFAS Volume 2: Appendices A & B, 02 May April 2018.
  - PFAS Volume 3: Appendices C to I, 02 May 2018.
- WSP (2018b), RAAF Townsville Seasonal Monitoring Report 1 – PFAS. WSP Australia Pty Ltd.
  - PFAS Volume 1: Main Report, 18 December 2018.
  - PFAS Volume 2: Appendices A & B, 18 December 2018.
  - PFAS Volume 3: Appendices C & D, 18 December 2018.
  - PFAS Volume 4: Appendices E, 18 December 2018.
- WSP (2018d), RAAF Base Townsville – PFAS Investigation Semi-Terrestrial Biota Sampling and Analysis, June 2018. WSP Australia Pty Ltd.

Wet season data is presented in the Seasonal Monitoring Report 1 (WSP 2018b) and the wet season data for groundwater, surface water and sediments has also been incorporated into this ERA report, with tabulated result tables presented in Appendix B. Potential risks to ecological receptors were quantitatively assessed using the wet season groundwater, surface water and sediment results. No additional aquatic biota samples were collected during the wet season.

2.2 KEY ASSUMPTIONS AND LIMITATIONS OF THE ERA

This ERA is based on the following key assumptions and limitations:

- The outcomes of the ERA are based on current concentrations as measured throughout the DSI (WSP, 2018a and 2018b) and during aquatic and semi-terrestrial biota sampling events. Therefore, the ERA cannot evaluate potential risks to ecological receptors as a result of changes in PFAS concentrations in the environment since collection of the DSI data and biota samples. Similarly, the ERA has not considered any cumulative impacts to ecological receptors from historical exposure as this is not considered possible (or plausible) as the concentrations within the various media were not known.
- The assessment of potential ecological risks was based on data obtained during the DSI (WSP, 2018a and 2018b), during the semi-terrestrial biota sampling event (WSP, 2018d) and ESP's aquatic biota sampling programs between July 2017 and March 2018.
- DSI (WSP, 2018a and 2018b) sampling and analysis that targeted both on-Base and off-Base media during the dry and wet season included soil, groundwater, sediment and surface water. Aquatic biota (i.e. finfish, crustaceans, plants and bivalves) samples were collected in the dry season and just prior to the start of the wet season, and semi-terrestrial biota samples were collected just prior to the start of the wet season. Hence, an evaluation for how PFAS concentrations may vary during seasonal changes was not undertaken. Aquatic biota sampling was also limited to seasonal availability of different fish species and accessibility for sampling.

- No site-specific sampling was undertaken for terrestrial invertebrate species (i.e. insects, earthworms etc.). However, earthworm data was utilised from AECOM (2016) as a substitute.
- The selection of receptors and species in which to sample and/or include within quantitative food web modelling were those which have an affinity with aquatic environments, as it is was assumed that they will have higher exposure to PFAS concentrations present within the environment, and were used to infer or consider potential risks to other trophic levels within only terrestrial environments.
- In the absence of site-specific data for some species/trophic groups including terrestrial vertebrates and herbivorous mammals, the adopted exposure point concentrations were based on available data from other completed Defence investigations, primarily from AECOM (2016). For terrestrial invertebrates, earthworm data was adopted as a substitute. For herbivorous mammals, rabbit tissue data from AECOM (2018), was adopted as a substitute.
- In the absence of available wild bird tissue or bird egg data, chicken egg data as reported in AECOM (2016) was adopted as a representative (substitute) exposure point concentration for quantitative modelling purposes.
- One of the primary uncertainty factors when undertaking food web modelling is the absence of species specific food and water ingestion rates for some Australian species. In the absence of Australian data, it is unclear whether the adopted assumptions would result in an under or over estimation of risks.
- Quantitative food web modelling for higher order species evaluates the potential exposure as a direct result of bioaccumulation of PFAS in the diet of terrestrial/semi-terrestrial and aquatic birds, reptiles and mammals. However, the additional exposure risk associated with biomagnification within higher order species cannot be accounted for or evaluated via food web models.
- The modelling of a receptor's exposure from ingestion of dietary items assumes all items contain PFAS, however it is more likely that not all dietary components would contain PFAS as they are sourced from different areas and seasonal variation may also occur.
- The whole Investigation Area has been assumed to be contaminated with the concentrations adopted at the point of exposure. This does not account for the range of reported concentrations for various media, as well as seasonal variability which appears to be occurring to some degree. This therefore likely results in conservative estimates of risks to ecological receptors.
- The home range value adopted was based on twice the size of the Investigation Area to account for migratory species which move to areas outside the Investigation Area. Given the extensive migration of some bird species (identified in the Investigation Area), the adopted home range value is considered very conservative and therefore likely results in an overestimation of risks to migratory receptors.
- It has been assumed for modelling purposes that the proportion of available suitable habitat within the Investigation Area is 100%. This is considered to be conservative, as it is more likely the migratory species may move outside of the Investigation Area reducing their potential exposure to PFAS. This may result in conservative estimates of risks to these species, but is considered appropriate in the absence of specific data.
- Potential risks for reptiles considered as tertiary consumers (freshwater snake and Canns Longnecked turtle) was quantified using toxicity reference values for avian species as no toxicity or dose-response information is currently available for reptilian species. Little is also known about how they metabolise PFAS or other emerging chemicals. Hence the evaluation of risks to reptilian species via quantitative food web modelling may not be providing a conservative (or representative) risk estimate.
- Domestic animals (both farm and residential) have not been evaluated as part of the ERA as they are not considered to be exposed in the same way as wild ecological receptors (i.e. they are often fed food from other sources including food scraps and/or packaged pet food). They are likely to primarily drink tap water rather than bore water or surface water. Management measures can also be implemented to prevent exposure including the use of reticulated town water instead of groundwater, and supplementing food supply, so that animals are not eating produce grown in impacted soil, groundwater or surface water.

3 BACKGROUND AND HISTORY OF AFFF USE AT THE BASE

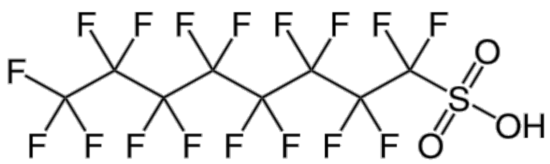
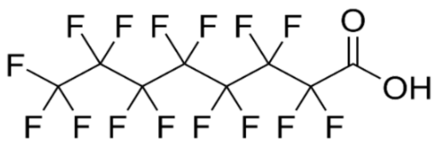
3.1 WHAT IS PFAS

As noted in Section 1 above, PFAS is the collective name given to a large group of chemicals with similar structure and properties. There are hundreds of chemicals that can be classed as PFAS. However, current commercial analytical methods can only detect a limited number of these.

PFAS are man-made compounds that do not occur naturally in the environment, are characterized by their fluorinated carbon chains where the hydrogen atoms have been replaced with fluorine atoms. The resulting carbon-fluorine bond ensures that PFAS are both highly resistant to being degraded or metabolized; and are bio-accumulative (ATSDR, 2015). Perfluorooctane sulfonate (PFOS) contains eight carbon atoms and a sulfonate group ($C_8 F_{17} SO_3$); and perfluorooctanoic acid (PFOA) also contains eight carbon atoms and is a persistent perfluorinated carboxylic acid ($C_8 HF_{15} O_2$). Both compounds are members of the PFAS group most commonly associated with historical AFFF (ATSDR 2015).

Of the PFAS compounds that were included within the analysis suite (i.e. 28 in total), sufficient toxicological information is (currently) only available for PFOS and PFOA to allow for the derivation of ecological protection guidelines. Hence, the quantitative evaluation of ecological risks related to PFAS (other than PFOS and PFOA) is not currently possible. Further discussion regarding the evaluation of other PFAS compounds is provided in Section 10.2. The chemical structure of PFOS and PFOA is provided in Table 3.1 below.

Table 3.1 Chemical structure of PFOS and PFOA

NAME	CHEMICAL FORMULA	CHEMICAL DIAGRAM
PFOS	$C_8HF_{17}O_3S$	
PFOA	$C_8HF_{15}O_2$	

3.2 PHYSICAL AND CHEMICAL PROPERTIES OF PFAS

PFOS and PFOA are manufactured chemicals that exhibit the following properties:

- ***Chemically and biologically stable*** – persistent in the environment and resistant to biodegradation, atmospheric photooxidation, direct photolysis and hydrolysis. However, note that dispersion will 'naturally dilute' PFAS concentrations proportional to the distance from the source of PFAS contamination.
- ***Moderately to highly soluble in water –*** (PFOA is highly soluble and PFOS is moderately soluble). Therefore, PFOS and PFOA are readily dissolved/leached from soils by infiltrating water (i.e. rainwater, surface water or groundwater) and move into receiving water (i.e. groundwater and surface water) in areas where they have been released into the environment.

- ***Highly mobile* –** PFAS show little chemical/physical retardation (i.e. adsorption and/or degradation) during transport (e.g. in surface water or groundwater). Therefore, once PFAS enters the environment it can be transported a significant distance from the source/release point.
- ***Not biodegradable* –** Biodegradation of PFAS compounds is not known to occur; however, microbial degradation or metabolic processes of larger organisms can form PFOS and PFOA through the breakdown of longer-chain 'precursor' compounds (i.e. 10:2 fluorotelomer sulfonate (FtS)) or related substances.
- ***Non-volatile* –** PFAS compounds generally have low volatility. Therefore, PFAS does not partition to soil vapour or the atmosphere.
- ***Permeation* –** PFAS can permeate some solid surfaces (e.g. concrete and other building materials). These materials can accumulate high concentrations of PFAS and act as a potential secondary source of contamination.
- ***Bioaccumulation*** – PFAS has been reported to bioaccumulate within the environment. Bioaccumulation occurs when an organism absorbs a substance at a rate faster than that at which the substance is lost by catabolism and excretion. Therefore, the reported concentration of PFAS within an animal can be greater than the concentration of PFAS within the environment (e.g. fish reporting a higher concentration of PFAS than the water in which it lives).

The combination of the above physical and chemical characteristics results in PFAS being readily transported from primary and secondary (soil and sediment) sources via groundwater/surface water and wide spread contamination of the surrounding environment (including biota). PFAS contamination can persist (within the environment) for many years (or decades) following the initial release.

3.3 GENERAL USE OF FIRE FIGHTING FOAM

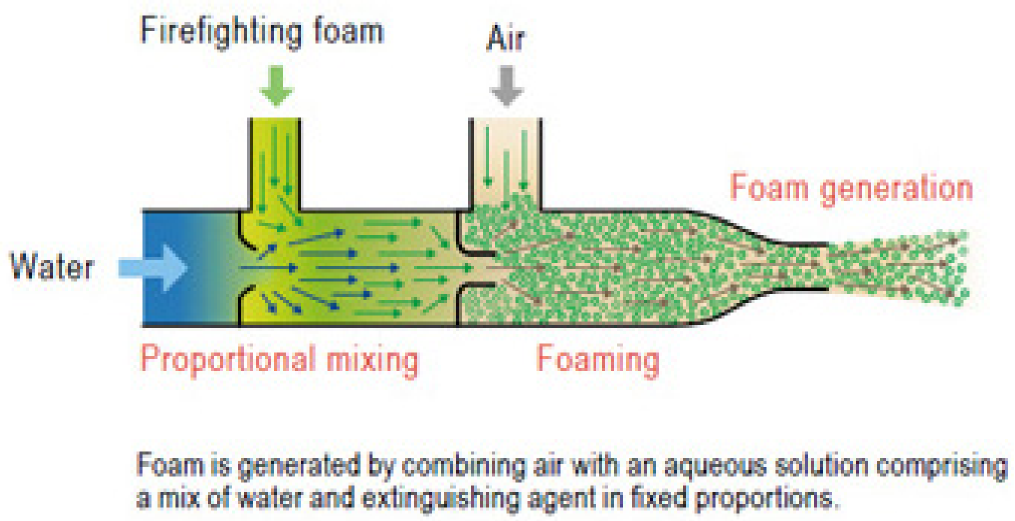
PFAS have been used in various industrial processes and consumer products since the 1950s. It is understood that PFAS were first used as a constituent of Aqueous Film Forming Foam (AFFF) in the late 1960's and by the mid 1970's was used widely internationally and within Australia by civilian and military authorities.

It is understood that the primary AFFF product in use at Defence sites until approximately 2004–2005 was 3M Lightwater™, which is known to contain many PFAS compounds, but is dominated by PFOS, PFHxS and to a lesser extent PFOA.

Ansulite® replaced 3M Lightwater™ at RAAF Base Townsville after 2004.

Firefighting foam (containing PFAS) was also widely used by other industries where flammable chemicals were present (e.g. petroleum and chemical sites) and civil fire authorities (e.g. vehicle accidents, industrial firefighting).

Firefighting foam works by 'smothering' the fuel source (e.g. burning object/liquid fuel) with a foam layer, extinguishing the flames and preventing further combustion. Firefighting foam can be applied over a large area very quickly, therefore mitigating property damage and loss of life better than other firefighting methods.



Note: This image was sourced from the internet and is not a representation of activities at RAAF Base Townsville.

Figure 3.1 Example how the foam delivery equipment produces foam via mixing the liquid 'foam' agent with water and air

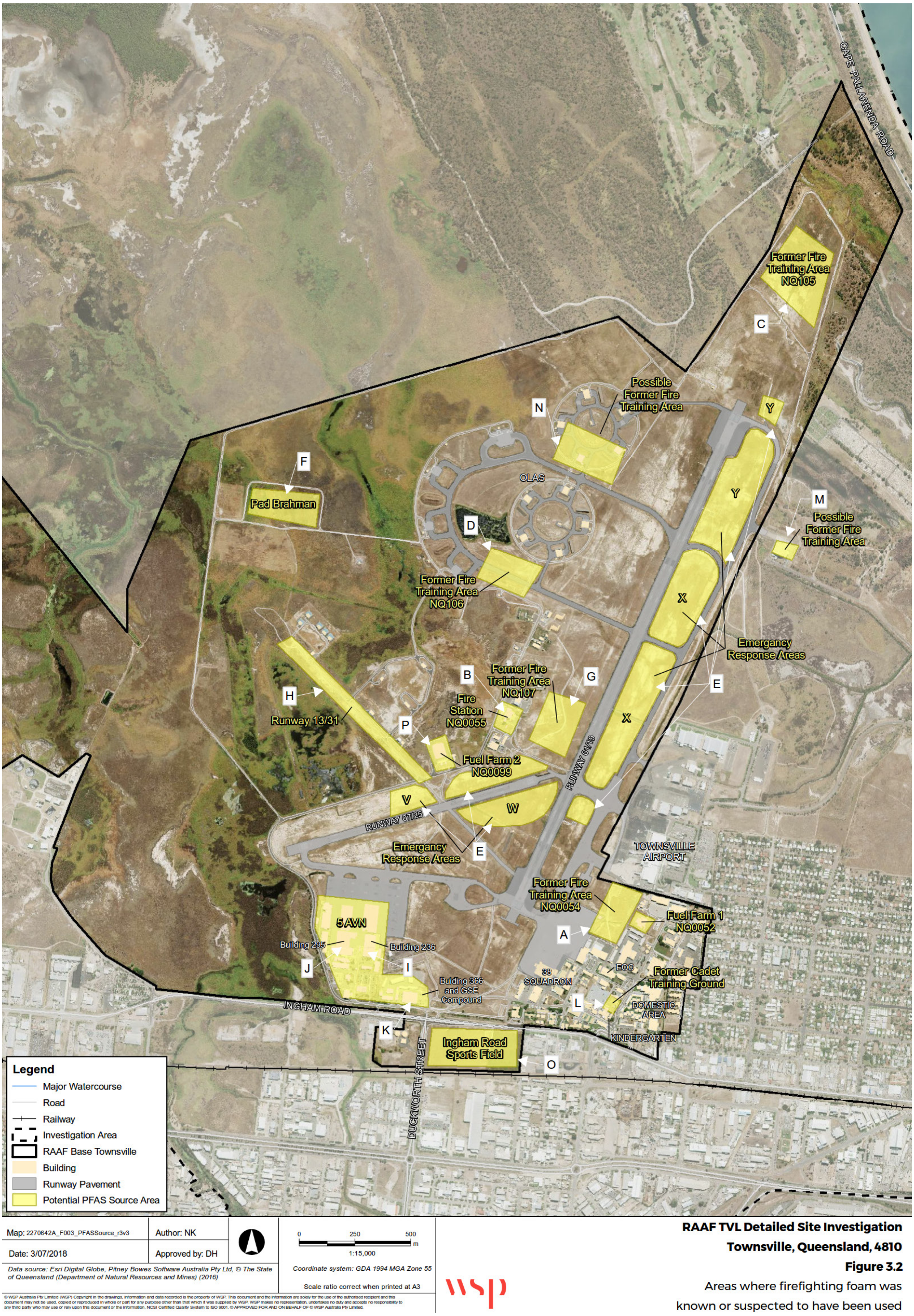
Firefighting foam is supplied and stored (prior to use) in a liquid form. During application, the firefighting foam 'liquid' is mixed with water and air (under pressure) and forced through a nozzle to create a foam (refer to Figure 3.1 above).

3.4 USE OF FIRE FIGHTING FOAM AT RAAF BASE TOWNSVILLE

The use of AFFF (containing PFAS) at RAAF Base Townsville was related to the following activities:

- ***Mobile firefighting capability*** – RAAF Base Townsville maintains an on-Base emergency firefighting capability related to aircraft operations. This includes:
  - ***Firefighting training*** – To maintain the firefighting capability, firefighting training was conducted on a regular basis (e.g. weekly)
  - ***Testing and maintenance of foam dispersion equipment*** – routine testing of fire-fighting equipment and testing of fire suppression systems on vehicles; and
  - ***Emergency response*** – Any situation where the firefighting capability was deployed, e.g. Aircraft accidents, fuel spills, etc.
- ***Above ground fuel farms*** – there was the potential for equipment testing and purging of fire truck tanks to have occurred within the fuel farm areas.
- ***Aircraft Hangers –*** Fixed fire suppression systems charged with AFFF were installed within several hangars located on RAAF Base Townsville.
- ***Open Day demonstrations –*** AFFF was discharged to the ground at several on-Base area's during annual "Open Day Demonstrations".

Potential source areas/activities are outlined in Figure 3.2 and discussed in more detail in Table 3.2.



Note: Figure extracted from Figure 3 of the WSP (2018a) DSI report.

Figure 3.2 Areas where firefighting foam was known or suspected to have been used

Table 3.2 Summary of potential firefighting foam use and identified impacts

AREA	LOCATION	POTENTIAL FOR FIREFIGHTING FOAM USE	PFAS CONCENTRATIONS IDENTIFIED (✓ / ×) [1]		
			SOIL/SEDIMENT	GROUNDWATER	SURFACE WATER
Aircraft Washing Facility and Former Fire Training Ground (NQ0054) *(Shown as **Area A** on Figure 3.2 above)*	Approximately 200 m to the east of the southern extent of the main runway (Runway 01/19).	Confirmed use.	✓	✓	✓
Fire Station (NQ0055) *(Shown as **Area B** on Figure 3.2 above)*	Located approximately 300 m west of the main runway (Runway 01/19) and 200 m north of Runway 07/25 (centrally located on Base).	Confirmed use.	✓	✓	✓
Former Fire Training Ground (NQ0105) *(Shown as **Area C** on Figure 3.2 above)*	Approximately 530 m north of the northern extent of the main runway (Runway 01/19).	Confirmed use.	✓	✓	✓
Former Fire Training Ground (NQ0106) *(Shown as **Area D** on Figure 3.2 above)*	Approximately 540 m west of the main runway (Runway 01/19) and south of the ordnance loading aprons (OLAs).	Confirmed use.	✓	✓	✓
Emergency Responses – Runway 07/25 and Runway 01/19 *(Shown as **Area E** on Figure 3.2 above)*	Various locations across the Base (exact locations and number of emergency response events is not known).	Confirmed use.	✓	✓	✓
Pad Brahman *(Shown as **Area F** on Figure 3.2 above)*	Located within the north-western corner of the base (to the northwest of the base runways).	Likely use.	✓	✓	✓
Fire Training Area Site Q (NQ0107) *(Shown as **Area G** on Figure 3.2 above)*	Located adjacent to the west of the main runway (Runway 01/19) and to the east of the Fire Station.	Confirmed use.	✓	✓	No surface water sample obtained as no surface water body present [2]

AREA	LOCATION	POTENTIAL FOR FIREFIGHTING FOAM USE	PFAS CONCENTRATIONS IDENTIFIED (✓ / ×) (1)		
			SOIL/SEDIMENT	GROUNDWATER	SURFACE WATER
Disused Runway 13/31 *(Shown as **Area H** on Figure 3.2 above)*	Located to the northwest of Runway 07/25.	Confirmed use.	✓	✓	✓ – south of disused runway
5 AVN C Squadron Hangar (Building 236) *(Shown as **Area I** on Figure 3.2 above)*	Approximately 650 m west-south-west from the southern extent of the main runway (Runway 01/19).	Confirmed use.	✓	✓	✓
5 AVN A/B (Building 295) *(Shown as **Area J** on Figure 3.2 above)*	Approximately 750 m west-south-west from the southern extent of the main runway (Runway 01/19).	Confirmed use.	✓	✓	✓
5 AVN Wash Point (Building 366) and GSE Compound *(Shown as **Area K** on Figure 3.2 above)*	Approximately 600 south-west from the southern extent of the main runway (Runway 01/19).	Confirmed use.	✓	✓	✓
Former Cadet Training Area (Domestic Area) *(Shown as **Area L** on Figure 3.2 above)*	Approximately 550 m south-east from the southern extent of the main runway (Runway 01/19).	Confirmed use.	✓	✓	✓
Former Fire Training Area *(Shown as **Area M** on Figure 3.2 above)*	Approximately 400 m east from the northern portion of the main runway (Runway 01/19) (now Off-Base).	Possible use.	NA(2)	NA(2)	NA(2)
Former Fire Training Area *(Shown as **Area N** on Figure 3.2 above)*	North of the OLAs, approximately 450 m east from the northern extent of the main runway (Runway 01/19).	Possible use.	NA(2)	NA(2)	NA(2)
Defence Playing Fields – "Open Day Demonstrations" *Shown as **Area O** on Figure 3.2 above)*	Adjacent to the southern side of Ingham Road, east of Duckworth Street.	Confirmed use.	✓	✓	✓ – south-west of sports field

AREA	LOCATION	POTENTIAL FOR FIREFIGHTING FOAM USE	PFAS CONCENTRATIONS IDENTIFIED (✓ / ×) (1)		
			SOIL/SEDIMENT	GROUNDWATER	SURFACE WATER
Fuel Farm 2 (NQ0099) *(Shown as **Area P** on Figure 3.2 above)*	Fuel Farm 2 is located to the north of Runway 07/25.	Likely use.	✓	✓	No surface water sample obtained as no surface water body present

(1) ✓ = detected × = below laboratory reporting limits. Based on identified PFAS concentrations in the DSI (WSP 2018a).

(2) NA – indicates not applicable as no sampling of relevant media undertaken within specific area. Refer to Section 8.7 for details regarding the suitability of the datasets for the ERA.

3.4.1 OTHER POTENTIAL SOURCES OF CONTAMINATION

Other diffuse or unidentified sources may also be present, for example:

- daily testing of equipment and sparging of tanks; mostly undertaken between the fire station and Runway 01/19, multiple “random’ locations along roadways were used on occasion to provide a variety of scenarios
- spills, including the following two reported incidents (it is noted that Defence personnel suggested that neither of these spills were ‘cleaned-up; and that the AFFF seeped into the ground):
  - a spill of approximately 200 L of dilute AFFF from a fire truck at the front (eastern side) of the fire station, which ponded in the depression next to the access road to the south-east of the fire station; and
  - a spill of approximately 50 L of dilute AFFF from a fire truck that ran beneath the aircraft body on the southern side of disused Runway 13/31
- potential for equipment and sparging of fire truck tanks to have occurred at Fuel Farm 1.

4 IDENTIFICATION OF THE INVESTIGATION AREA

4.1 GENERAL LOCATION

RAAF Base Townsville is located approximately 5 km west-north-west of the Townsville CBD in Queensland. It covers an area of approximately 738 hectares (ha) and is a joint use military and civilian airfield facility. A site layout plan is provided in Figure 2, Appendix A.

The Investigation Area is not specifically defined by survey, but is generally the area shown on Figure 4.1 and comprises:

- The RAAF Base Townsville
- Townsville Airport
- TCC areas (including residential communities); and
- The Ecological area, consisting of the Town Common and the Bohle River estuary and banks upstream to the Bruce Highway Bridge (Ingham Road).

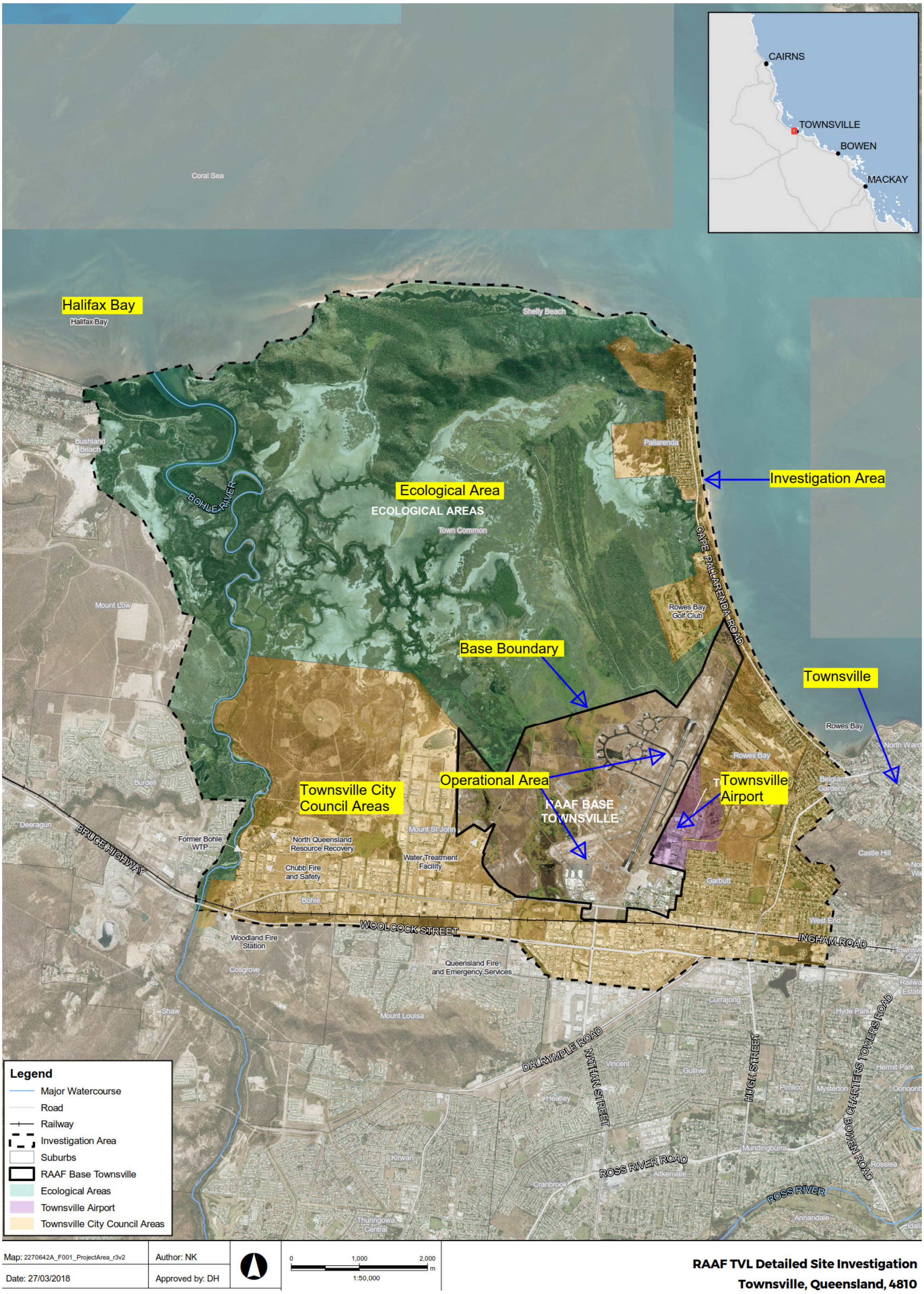


Figure 4.1 Nominated Investigation Area (aerial view). The Investigation Area is identified as the area within the black dashed line. The Base boundary is shown as the solid black line

The rationale for the selected Investigation Area boundaries is summarised in Table 4.1 below.

Table 4.1 Rationale for nomination of investigation area boundaries

AREA BOUNDARY	DESCRIPTION/RATIONALE
East – Off-Base	**Description:** *Townsville Airport* **Rationale:** No confirmed potential PFAS source areas are known on Townsville Airport. However, the grassed area in the northern section of the airport may have been used to clean fire-fighting equipment, including cleaning out AFFF tanks (GHD 2011). Townsville Airport shares the same runway (Runway 01/19) as the Base, the drains near the runway and on the eastern border of the Base, run through Townsville Airport, into Rowes Bay and exit at Mundy Creek. Groundwater flow directions from nearby potential PFAS source zones (namely the Former Training Area NQ0054, the Cadet Training Ground and Fuel Farm 1 (as described in Section 3.4) were reported to potentially vary from north-westerly to easterly. Therefore, given the above factors, the likelihood of PFAS migrating towards the Townsville Airport from the Base is considered moderate to high.
East, South and West – Off-Base	**Description:** *Townsville City Council (TCC) Areas* The TCC areas located within the Investigation Area include the suburbs of Mt St John, Bohle, Pallarenda and Rowes Bay, and parts of Belgian Gardens, Garbutt, West End, Mount Louisa, and Cosgrove, and has an area of approximately 2,506 ha. The suburbs of Pallarenda, Rowes Bay, West End and Belgian Gardens are primarily residential. However, various public facilities and parklands also exist within these suburbs. **Rationale:** There are likely to be background off-Base sources of PFAS from the TCC areas within the Investigation Area and these are discussed further in Section 4.1.1. Groundwater flow directions from nearby potential PFAS source zones (namely the Former Training Area NQ0054, the Cadet Training Ground and Fuel Farm 1 (as described in Section 3.4) were reported to potentially vary from north-westerly to easterly. Therefore, given the above factors, the likelihood of PFAS migrating towards the suburb of Garbutt from the Base is considered moderate to high.

AREA BOUNDARY	DESCRIPTION/RATIONALE
North and North-west – Off-Base	**Description:** *Ecological Area* The part of the Investigation Area referred to as the 'Ecological Area' comprises: — the Town Common, which is zoned "Public Utilities – Townsville City Council (Reserves)" and "Special Uses – National Parks" (TCC 2014) — the Bohle River and Bohle River estuary, which is unzoned; and — the banks of the Bohle River and Bohle River Estuary, including parts of the suburbs of Bushland Beach, Mount Low, Burdell, Bohle and Cosgrove. The zoning for this land is either "Vacant Land", "Rural – Cattle Grazing (Breeding & Fattening)" or "Special Uses – Parks and Recreation (Reserves)" (TCC 2014). The total area of the Ecological Area is approximately 4,460 ha. **Rationale:** The Town Common was historically used for the grazing of cattle; however, this practice was halted in the 1990s and all "wild" cattle were removed from the Town Common in the 2000s. The Ecological Area of the Investigation Area includes a large part of the estuarine system and drainage from the Bohle River, including Peewee Creek, Louisa Creek, and Three Mile Creek. Within the Town Common, a 1.07 ha perennial lake is located near Causeway Road and Freshwater Lagoon Road. There are approximately three rural water storage areas throughout the Town Common. The Town Common receives surface water run-off from the Base and from the TCC suburbs of Bohle, Mount St John (including the water treatment plant) Louisa and parts of Garbutt. Groundwater flow from the Base is partially radial, being westward from 5 AVN, north-westerly from the fire station and OLAs, north-easterly from Townsville Airport and easterly from the domestic area of the Base. Groundwater flows westerly to Peewee Creek/Louisa Creek, north-westerly to the Town Common wetlands and north-easterly and easterly to the Mundy Creek catchment and Rowes Bay. Therefore, given the above factors, the likelihood of PFAS migrating towards the Ecological Area from the Base (and potentially the TCC areas) is considered moderate to high. *NB: Based on previous activities conducted within the Town Common which included cattle grazing and given that the Mount St John water treatment plant also discharges treated effluent into the Town Common, the environment is considered to be degraded and altered from its previous pristine condition (i.e. pre-European farming/settlement).*

4.1.1 POTENTIAL OFF-BASE SOURCES WITHIN THE TCC AREA

There are likely to be background Off-Base sources of PFAS from the Townsville City Council Areas within the Investigation Area, which are discussed below (Table 4.2) for context and depicted within Figure 4.2.

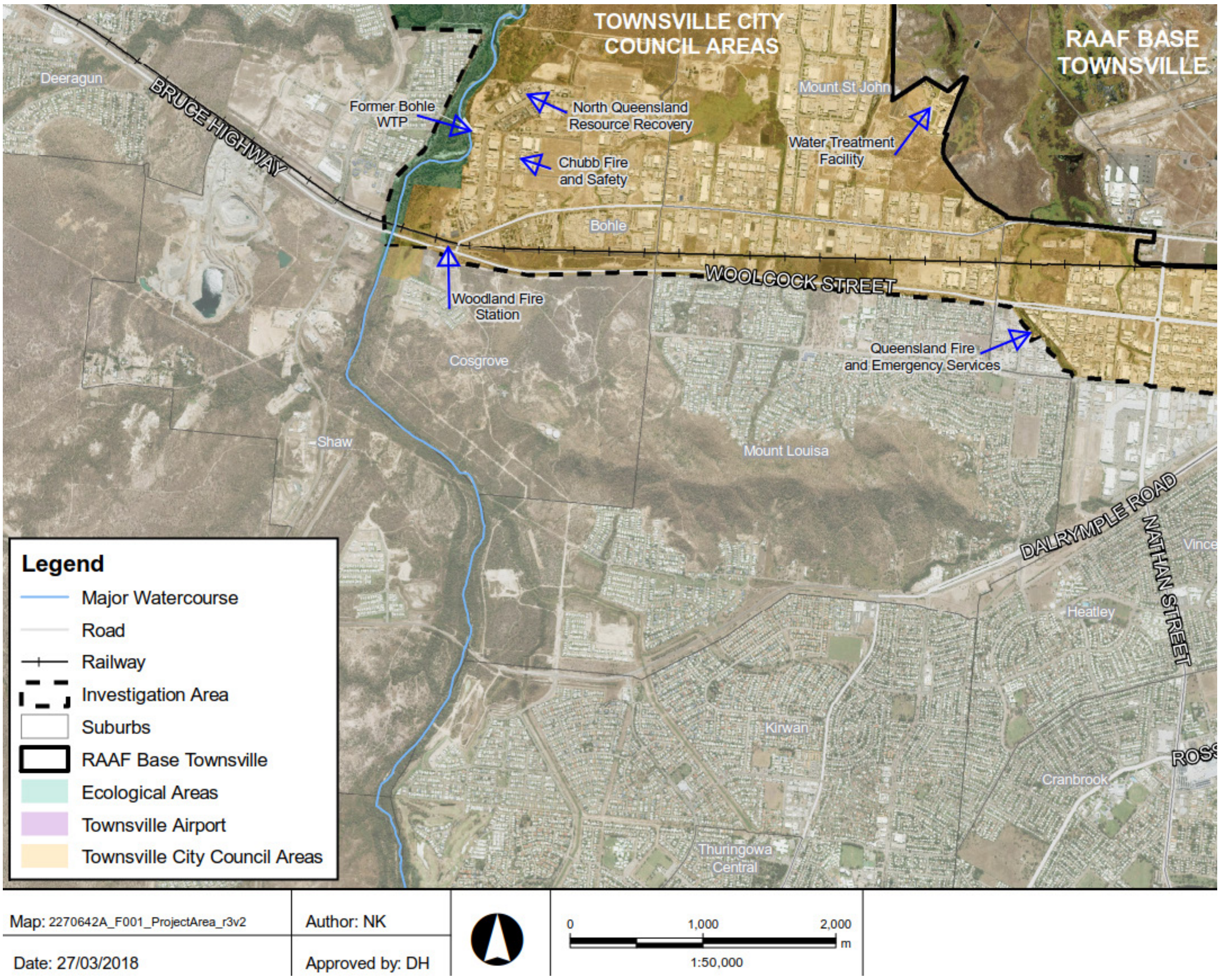


Figure 4.2 Potential background Off-Base sources of PFAS from the TCC Areas within the investigation area (aerial view)

Table 4.2 Potential off-Base PFAS sources within the TCC areas

FEATURE	DESCRIPTION
Woodlands Fire Station	Where AFFF handling and fire training may occur.
Queensland Fire and Emergency Services Northern Region Mechanical Workshop	Where AFFF handling and fire training may occur.
Mount St John Water Treatment Plant (WTP)	Mount St John WTP where treatment of PFAS contaminated water may have occurred. The plant discharges water to the Town Common and eventually the Bohle River via an open drain/creek. Treated water is also piped to the Rowes Bay Golf Club for irrigation purposes. The PFAS removal efficacy for the WTP is not known. Trade waste from industrial sites in Bohle will be treated at Mount St John WTP and so whilst some point sources may not have discharged to ground, there is the potential that PFAS from their operations may have inadvertently been discharged into the environment via current and former water treatment facilities. The disposal fate of biosolids from the WTP is not currently known and if some or all of this disposal is located within the vicinity of the Investigation Area, it may also serve as a secondary source of PFAS into the environment.
Rowes Bay Golf Club	Treated water from the Mount St John WTP is piped to the Rowes Bay Golf Club for use as irrigational water; and the PFAS removal efficacy for the WTP is not known. As the Rowes Bay Golf Club is proximate to the on-Base Rowes Bay Landfill and the surface water discharge point, which discharges water from the northern end of the Base, the golf club may be a confounder to the assessment in the northern portion of the Base.
North Queensland Resource Recovery Centre	Waste soil and water received by the facility may contain PFAS.
Chubb Fire and Safety	Where AFFF handling and storage may occur.
The former Bohle WTP	The former Bohle WTP, which was operational prior to the commissioning of the Mount St John WTP, may have treated PFAS-impacted water. The former Bohle WTP discharged directly into the Bohle River.

4.2 OTHER GEOGRAPHIC LANDMARKS NOTED BY THIS REPORT

Several other geographic locations are noted/discussed within this ERA report; these features are described below in Figure 4.3 and Table 4.3 for context.

Figure 4.3 Geographic features and areas of interest referred to within this report (aerial view)

Table 4.3 Geographic feature and description

FEATURE	DESCRIPTION
Belgian Gardens	Belgian Gardens is primarily a residential suburb, located approximately 1.5 km east from the site.
Bohle River	The Bohle River and estuary (as a receiving body of the Louisa Creek) is one of the four primary receiving surface water catchments of the Investigation Area. The Bohle River is located approximately 5 km east of the operational areas of the Base. The Bohle river traverses north discharging to Halifax Bay, approximately 7.5 km north of the Bruce Highway bridge. Surface water from the western portion of the Base drains directly into Peewee and Louisa Creeks and the Town Common to the Base's west and north-west, eventually discharging to Halifax Bay via the Bohle River estuary. During the assessment works (DSI report, WSP 2018a), the upper reaches of the Bohle River was the only watercourse in the Investigation Area to have observable fresh flowing water that was not tidally influenced.
Cleveland Bay	Cleveland Bay is located within the Coral Sea, east of Rowes Bay. Cleveland Bay is expected to receive water from the following receptors: — The Town Common — Three Mile Creek and associated wetlands — Mundy Creek and associated wetlands.
Garbutt	The suburb of Garbutt includes the Base and Townsville Airport and is a mix of approximately 50% residential and 50% commercial/light industrial land use. The suburb also includes Garbutt State School.
Halifax Bay	Halifax Bay receive waters from the following receptors: — The Town Common — Louisa Creek and associated wetlands (including Peewee Creek) — Bohle River.
Louisa Creek	Louisa Creek runs along the western side of the base and is one of the four primary receiving surface water catchments of the Investigation Area. During the assessment works (DSI, 2018a), the upper reaches of Louisa Creek had no running water and was heavily reed and weed infested. The discharge from the Mount St John WTP enters Louisa Creek approximately 800 m downstream of the Base, and water was observed to be flowing intermittently downstream of this point. Tidal influence was observed approximately 2 km downstream of the discharge point, and mangroves line the creek banks downstream from this location. Fish and invertebrates were commonly observed downstream of the tidal zone.
Mount Saint John Drain	Drainage of a catchment to the west enters the Base through the Mount St John Drain. The Mount St John Drain is separated from Louisa Creek by an elevated ridge line and the Mount St John water treatment plant (WTP). The primary flow path of the drain is north, away from the Base. However, in high flow events there is potential for flow to back up around the ridge line into Louisa Creek, impacting the Base.

FEATURE	DESCRIPTION
Mundy Creek	Mundy Creek is located east from the Base and is one of the four-primary receiving surface water catchments within the Investigation Area. A network of drains in the south-east corner of the Base flow Off-Base to the east and then north into the Mundy Creek catchment and, in turn, Rowes Bay. A drainage network runs north between Runway 01/19 and the eastern boundary of the Base. These drains run north and south and discharge into the drain at the end of Old Common Road. This watercourse flows east into Mundy Creek and then Rowes Bay.
Pallarenda	Pallarenda is primarily a residential suburb, located 3.5 km north from the Base.
Peewee Creek	Peewee Creek drains mostly an urban catchment of 156 ha to the south-east of the Base. It is a small urbanised water course that terminates at Ingham Road and flows into Louisa Creek via culverts under Blakey Street; however, in high flow events it flows directly into the Base, overtopping Ingham Road.
Rowes Bay (suburb)	Rowes Bay is primarily a residential suburb, located adjacent to the eastern Base boundary.
Rowes Bay (water feature)	Rowes Bay receive waters from the following receptors: — The Town Common — Three Mile Creek and associated wetlands — Mundy Creek and associated wetlands.
Three Mile Creek	Three Mile Creek is located north from the Base and is another one of the four-primary receiving surface water catchments within the Investigation Area. A drainage network runs north between the OLAs and Runway 01/19, which discharges from the Base through valved pipework on the Base's northern boundary. The discharge then runs northerly through a network of wetlands past the Rowes Bay Golf Club and into Three Mile Creek. A drain runs along the Base's eastern boundary at the northern end of the Base beyond Runway 01/19 and discharges at the Base's north-eastern corner into the wetlands that run north past Rowes Bay Golf Club.
Town Common	Most of the Town Common is designated a Conservation Park under the *Nature Conservation Act 1992*. The Town Common and the estuarine reaches of the Bohle River are part of the Bohle River Fish Habitat Area (FHA-027), which is designated 'Management Level B' (NPSR 2012) for its importance to recreational, traditional and commercial fisheries (NPSR 2012). The estuarine reaches of the Town Common are mapped as having a very high aquatic conservation value under the Queensland Aquatic Conservation Assessment (AquaBAAM) mapping (Rollason and Howell 2012). The freshwater wetlands are mapped as having high ecological significance and matters of State environmental significance (MSES) under the State Planning Policy (SPP) (DILGP 2018). The Town Common is classified 'Category B – Remnant vegetation' on the Regulated Vegetation Management Map, with a section at the centre of the Town Common classified as 'Essential Habitat Category A or B'. Further details regarding terrestrial and aquatic habitats present within the Town Common are provided in Sections 6.1 and 6.2.

5 MOVEMENT OF PFAS WITHIN THE ENVIRONMENT

5.1 GENERAL

As noted in Section 3.2, PFAS have several unique properties that result in its widespread distribution and persistence within the environment.

The first stage of the distribution process occurs following the initial release of foam (containing PFAS) into the environment. The example below provides a simple cross section illustration of how this first stage occurs and results in contamination of **soil**, **surface water** and **groundwater** within the immediate vicinity of the point of release.

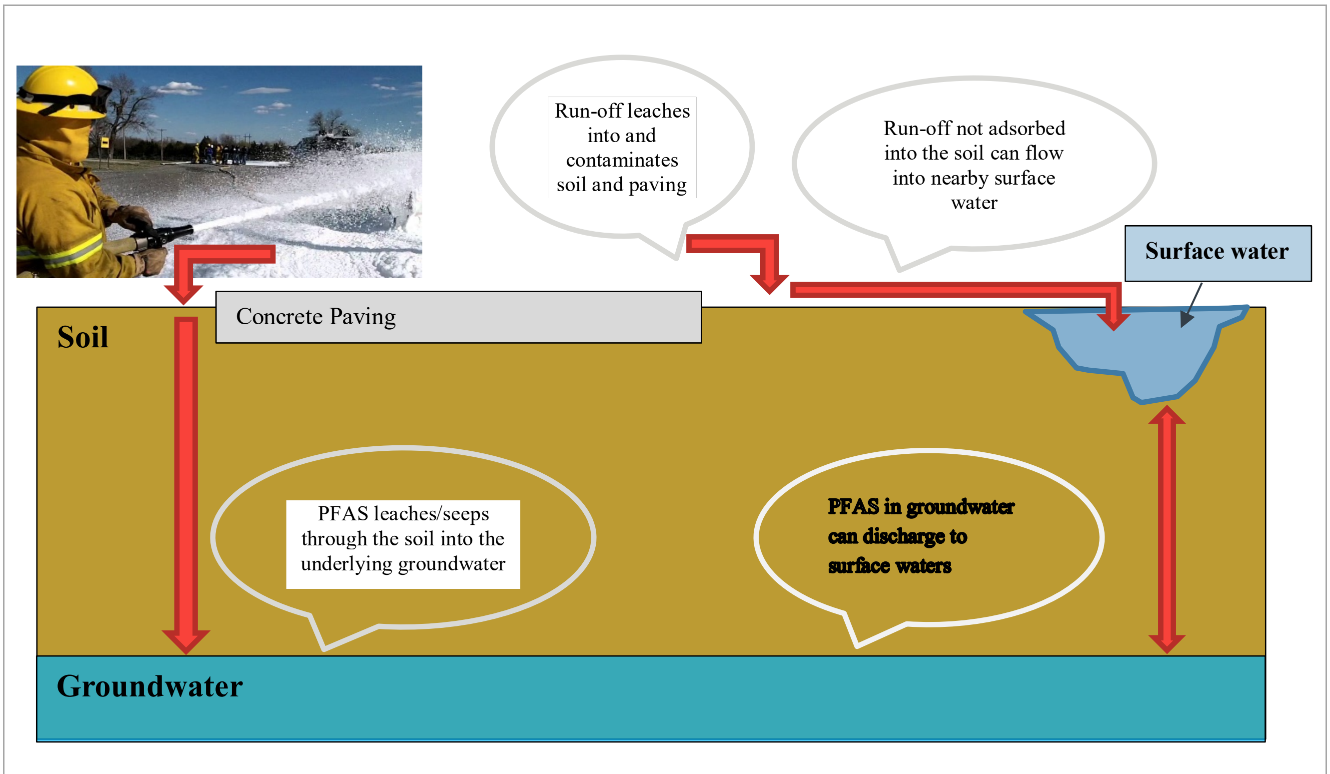


Figure 5.1 Simple illustration depicting the initial release of PFAS into the environment. Image of firefighter obtained from the Fire 247 website: https://www.fire24seven.com/

Following the initial release, PFAS can then move through the environment via the following mechanisms:

- **Surface water movement** – PFAS dissolved in surface water will move in the same direction and at the same rate as surface water flow.
- **Groundwater movement** – PFAS dissolved in groundwater will move in the same direction and at the same rate as groundwater flow. However, the surfactant properties of PFAS can also result in some lateral (or cross hydraulic gradient movement).

- **Interaction between groundwater and surface water:**
  - *Surface water* – When traveling over permeable soils, surface waters (containing PFAS) will seep into the underlying soils. This water will (in turn) migrate vertically to the underlying groundwater.
    Therefore, the surface water becomes a 'secondary' source of PFAS contamination that can cause groundwater contamination in areas not directly down hydraulic gradient (for groundwater) of the original source/release point.
  - *Groundwater* – Similarly, groundwater containing PFAS may also discharge to a surface water body resulting in contamination of the surface water (e.g. where groundwater discharges into the Bohle River).
  - *Seasonal variation* – In a tropical climate, the interaction between groundwater and surface water can vary significantly between/during seasons. Therefore, the extent and magnitude of PFAS within groundwater and surface water can also vary.
- **Soil movement** – Natural soil movement (i.e. via wind) is generally not a significant transport mechanism in vegetated (or semi vegetated areas).
- **Biota** – Uptake of PFAS by plants and animals (i.e. biota) can occur via several different mechanisms. However, the predominant pathway is understood to be ingestion of water and consumption of other animals that contain PFAS. As noted in Section 3.2 above, PFAS can bioaccumulate in biota resulting in the biota reporting higher concentrations (of PFAS) than the surrounding environment.
- Movement (or migration) of biota throughout the habitat may also result in the distribution of PFAS within the environment (i.e. via excretion or decay).
- For example, fish will move throughout available waterways. During its lifecycle, it will ingest and excrete PFAS, and at the end of its lifecycle any PFAS stored within the body of the fish will be released back into the environment as it decays. Individually, the amount of PFAS released would not be significant, however, when considering the total biomass across the Investigation Area, this potential secondary source may become significant.
- **Bioaccumulation and Biomagnification within the Food Chain:**
  - The transfer of PFAS within the food chain occurs via the interaction between lower order species and higher order species. Whereby PFAS that has bioaccumulated in lower order species, will be transferred and biomagnify up through the food chain, due to higher order species consuming lower order species, as part of their dietary intake.

5.2 ENVIRONMENTAL FACTORS RELEVANT TO PFAS DISTRIBUTION WITHIN THE INVESTIGATION AREA

As noted in Section 5.1, the distribution of PFAS within the environment is subject to several mechanisms that are dependent upon the media (i.e. soil, surface water and groundwater) that has been contaminated. Environmental factors relevant to each media and therefore the distribution of PFAS from RAAF Base Townsville are discussed in more detail below.

5.2.1 CLIMATE

Townsville (and the surrounding region) has a tropical climate with distinct wet and dry seasons. However, due to its geographical location, rainfall is not as high as elsewhere in the tropics.

The dry season generally occurs between May and September, where rainfall events are rare. During the dry season, large rivers (e.g. the Bohle River) maintain a low water level and flow. However, non-tidally influenced sections of smaller surface water bodies (e.g. Louisa Creek, Mundy Creek and Three Mile Creek) stop flowing and become dry.

The wet monsoon season occurs between December and March. During the wet season, high surface water flows are experienced with many surface water bodies reporting high levels and flow rates. However, the wet monsoon season did not commence until February 2018 and continued through to April 2018. Hence, data that was collected in January 2018 was included within the dry season results for the relevant media sampled. The data review (presented in Section 8) and reported concentration ranges for each media sampled (on and off-Base) has incorporated both dry and wet season data.

The cyclical tropical climate is an important factor to understanding the distribution of PFAS within the Investigation Area (as discussed in the following sections).

5.2.2 SURFACE WATER

5.2.2.1 FLOW AND RUN-OFF

The Investigation Area has four main surface water catchments, the Bohle River drainage sub-basin, Three Mile Creek, Mundy Creek and Louisa Creek, which are shown on Figure 5.2 below and Figures 3a and 3b, Appendix A.

5.2.2.2 SURFACE WATER RUN-OFF FROM THE BASE

The location of the Bohle River, Louisa Creek, Mundy Creek, Three Mile Creek and wetlands On-Base and within the Town Common are shown in Figure 5.2 below.

An investigation of the Base hydrology by SMEC (2012a; 2012b) reported:

- The internal catchment of the Base catchment is approximately 700 ha, most of which drains towards the north-west into the Louisa Creek flood plain and the Bohle Estuary. The catchment is made up of mostly mix grassed and wetland areas, including Lake Lydeamore, with the remainder being buildings and hardstand. There are localised drainage issues within the south-western section of the Base due to the concentrated proportion of impervious area (5 AVN) and minimum hydraulic capacity of the drainage network. The on-Base wetlands are generally internally draining, only discharging at times of heavy rainfall.
- A network of drains in the south-east corner of the Base flow off-Base to the east and then north into the Mundy Creek catchment and, in turn, Rowes Bay. The catchment consists of a mixture of hardstand, buildings and grassed areas, the largest grassed area being the former firefighting grounds (NQ0054).
- A drainage network runs north between the OLAs and Runway 01/19, which discharges from the Base through valved pipework on the Base's northern boundary. The discharge then runs northerly through a network of wetlands past the Rowes Bay Golf Club and into Three Mile Creek. A drain runs along the Base's eastern boundary at the northern end of the Base beyond Runway 01/19 and discharges at the Base's north-eastern corner into the wetlands that run north past Rowes Bay Golf Club.
- A drainage network runs north between Runway 01/19 and the eastern boundary of the Base. These drains run north and south and discharge into the drain at the end of Old Common Road. This watercourse flows east into Mundy Creek and then Rowes Bay.
- The area to the north of Runway 01/19 along the eastern boundary of the Base appears to drain east into the watercourse that runs south-east to the north of the Belgian Gardens Cemetery, joining Mundy Creek before flowing into Rowes Bay.

Sections of the Base adjacent to the runways subject to inundation have pumping networks designed to prevent flooding of the runways. Surface waters are pumped from sumps into the wetlands on the western, north-western and northern sides of the Base.

Therefore, any PFAS contaminated surface water run-off from the Base is likely to have followed a similar collection/distribution pattern as the surface water collection system and discharged to wetlands within the Town Common, Louisa Creek, Mundy Creek and/or Three Mile Creek (and ultimately the Bohle River/Halifax Bay and Rowes Bay). As noted in Section 5.2.1, Seasonal rainfall events would likely have also contributed PFAS distribution in a periodic/cyclical manner rather than a continuous one.

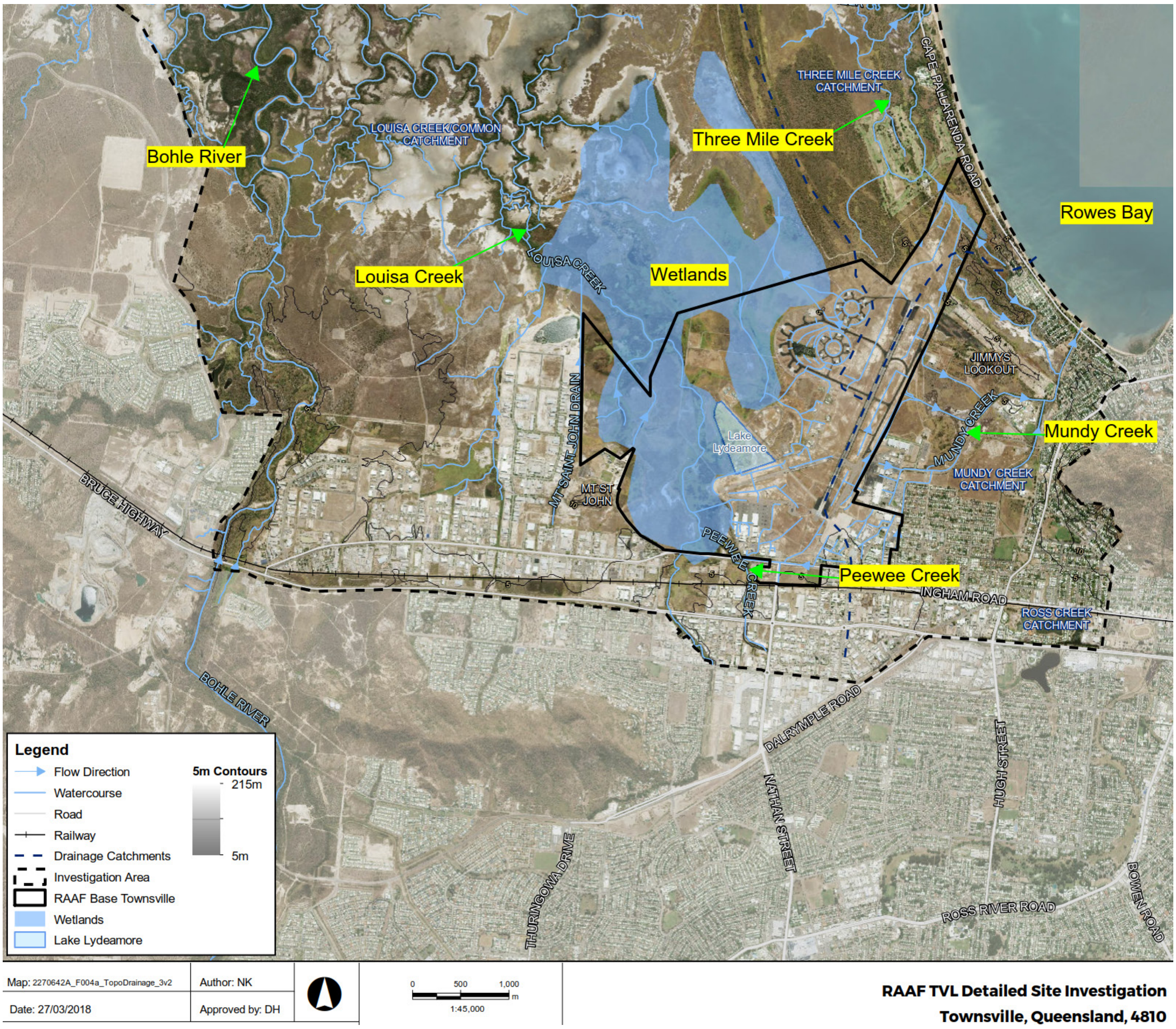


Figure 5.2 Overview of surface water features and flow (aerial view)

5.2.2.3 BOHLE RIVER

The location of the Bohle River is shown on Figure 5.2 above.

Surface water from the Base drains directly into Peewee and Louisa Creeks and the Town Common to the Base's west and north-west, eventually discharging to Halifax Bay via the Bohle River estuary.

Therefore, the Bohle River is a potential receptor of surface water contaminated with PFAS.

5.2.2.4 ROWES BAY AND HALIFAX BAY

The location of Rowes Bay is shown on Figure 5.2 above and the Bohle River discharges in the north to Halifax Bay.

Rowes Bay and Halifax Bay receive waters from one or more of the following receptors:

- The Town Common
- Louisa Creek and associated wetlands (including Peewee Creek)
- Three Mile Creek and associated wetlands
- Mundy Creek and associated wetlands; and
- Bohle River.

The bays (Rowes and Halifax) are considered to be secondary surface water receptors and were not directly assessed as part of the DSI (WSP, 2018a). However, to support both the human health and ecological risk assessments, aquatic biota were sampled from Rowes Bay including estuarine and marine areas to evaluate potential impacts on biota.

5.2.2.5 SURFACE WATER USE

Several surface water bodies are present within the Investigation Area including The Bohle River, the Town Common, Three Mile Creek, Mundy Creek, Louisa Creek, Peewee Creek, Halifax Bay and Rowes Bay.

Some recreational use of the Bohle River, the Town Common, Three Mile Creek, Mundy Creek and Louisa Creek for swimming and recreational fishing occurs where the water bodies pass through, or near, private properties located within the TCC residential areas which incorporates the suburbs of Garbutt, Rowes Bay, Belgian Gardens and Pallarenda.

The inshore and offshore waters of the region (i.e. Halifax Bay, Rowes Bay and Cleveland Bay) are considered marginal or non-key production areas for commercial mud crab, spanner crab and blue swimmer crab fisheries (ESP, 2018a). A locally important commercial net fishery focussing on barramundi, threadfin salmon and grey mackerel is also known to operate in the region (ESP 2018a). Halifax Bay, Rowes Bay and Cleveland Bays are also utilised as recreational fishing areas.

5.2.3 GROUNDWATER

5.2.3.1 HYDROGEOLOGICAL SETTING

Most of the Base is underlain by coastal plain sediments comprised of interbedded clays, silts and sands, which form a connected, semi-confined aquifer across the Base, with a water depth of approximately 1.5 mBGL to 2.5 mBGL. A deeper aquifer comprised of fluvial sands and gravels is reportedly present beneath the shallow aquifer (SKM 2008) but was not confidently identified during the DSI (WSP, 2018a). The section of the Base to the north of the main runway (fire training ground NQ0105), along the shoreline of Cleveland Bay and the suburb of Rowes Bay; are underlain by sands described as a strand plain of shallow sand dunes along Rowes Bay (SKM, 2008).

The clay/silt/sand aquifer appears to have a depth at least that of the maximum depth of investigation, which was 11 mBGL in Garbutt and 8 mBGL on-Base. Therefore, the clay/silt/sand aquifer has a thickness of at least 5.5 m to 9.5 m. This aquifer was intersected below the coastal sands On-Base, at the Town Common, Rowes Bay and in Belgian Gardens, and is likely to underlie the sands beneath the coastal sand dunes. Similar material was intersected at Bohle, suggesting that the unit extends across the entire coastal plain between the coastal sands and the outcropping granites and volcanics of Castle Hill, Mount Louisa and Many Peaks Range.

The sand-hosted aquifer in Cleveland Bay, Rowes Bay and Pallarenda had a maximum depth of 6.5 mBGL in MW210, which was the maximum depth of investigation in this area. The sand aquifer is likely to be several metres thicker in the centre of the sand dunes running parallel to the coast, thinning both eastwards and westwards. The eastern extent of this aquifer is not known as it extends offshore beneath Cleveland Bay. The sand aquifer extends approximately 2 km inland in the Town Common and narrows to the south, extending approximately 1 km inland at the Base and 500 m inland at Rowes Bay and Belgian Gardens.

5.2.3.2 GROUNDWATER RECHARGE

Most of the Base has a sandy/silty clay shallow sub-surface, which implies that both rainfall infiltration through the surface soil and groundwater recharge would be slow. However, water level monitoring in 2008 (SKM 2008) revealed near-instantaneous groundwater responses to an 80 mm rainfall event, stabilising approximately 0.8 m higher within three to ten days. This suggests that the permeability of the shallow soils is higher than that expected by the field observations. The shallow depth to groundwater would facilitate recharge of the shallow aquifers. Townsville is subject to heavy rainfall events in the wet season, and standing water is present over much of the Base in a normal wet season, which would help to recharge the aquifer. Surface water discharge from the Base into the Town Common to the west/north-west and into Mundy Creek to the north-east is also expected to provide groundwater recharge from these water bodies.

Rainfall recharge of the sand-hosted aquifer at Cleveland Bay, Pallarenda and Rowes Bay is expected to be rapid due to the sandy nature of the sub-surface and the relatively shallow depth of groundwater. Water level monitoring at the former Rowes Bay landfill (SKM 2008) following an 80 mm rain event showed an approximate increase in groundwater levels of 0.4 m stabilising after 10 days. The response was almost instantaneous, but more subdued than in the monitoring wells screened in the silty/sandy clays on the Base.

5.2.3.3 GROUNDWATER FLOW AND DISCHARGE

Groundwater flow direction as provided in the DSI (WSP, 2018a), relative to potential surface water receptors is presented in Figure 5.3 and Figure 5.4 below:

Groundwater flow from the Base is considered partially radial, being westward from 5 AVN, north-westerly from the fire station and OLAs, north-easterly from Townsville Airport and easterly from the domestic area of the Base.

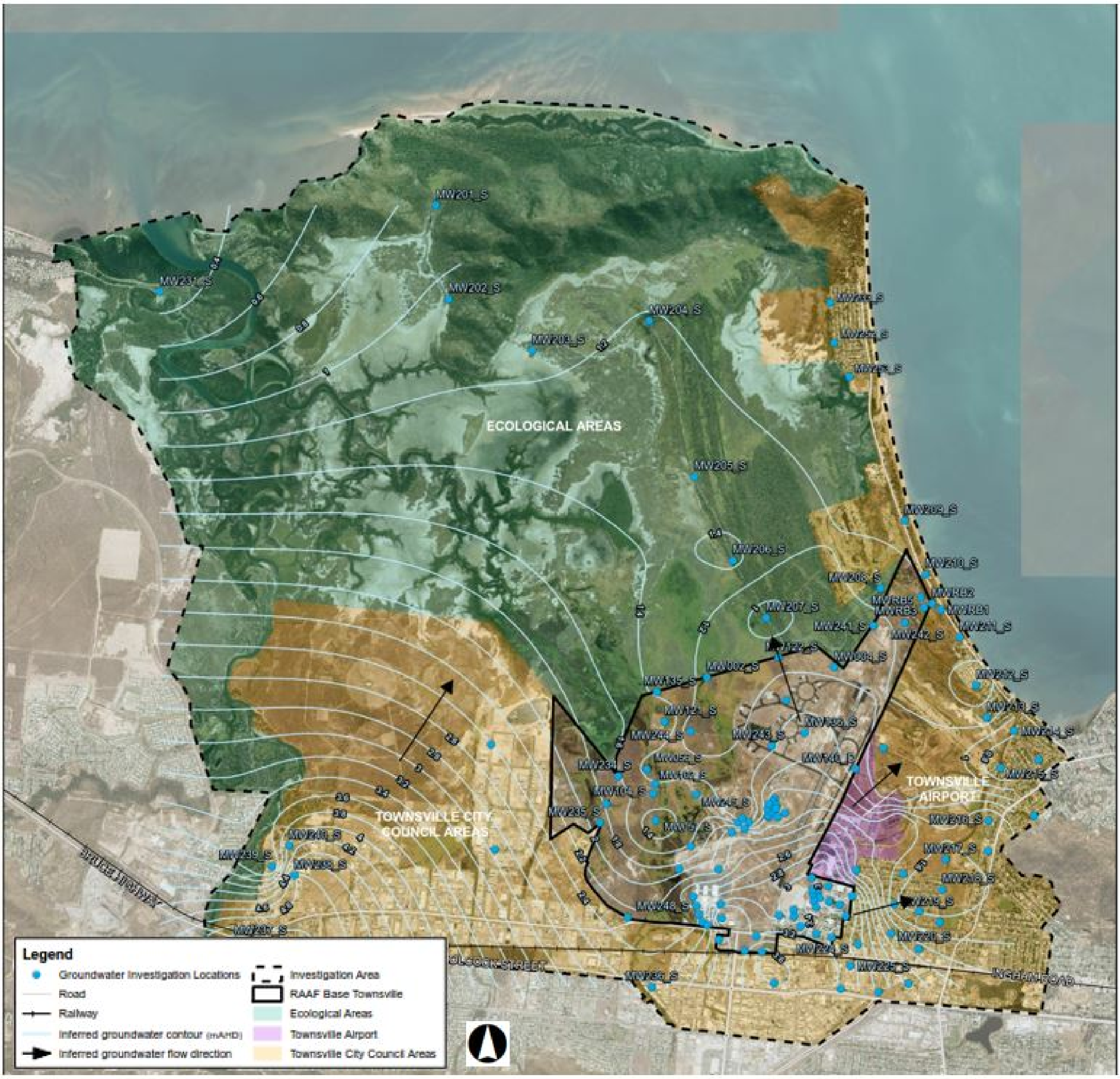


Figure 5.3 Overview of inferred groundwater flow direction across the Investigation Area (aerial view). Depicted groundwater contours are representative of the dry season only

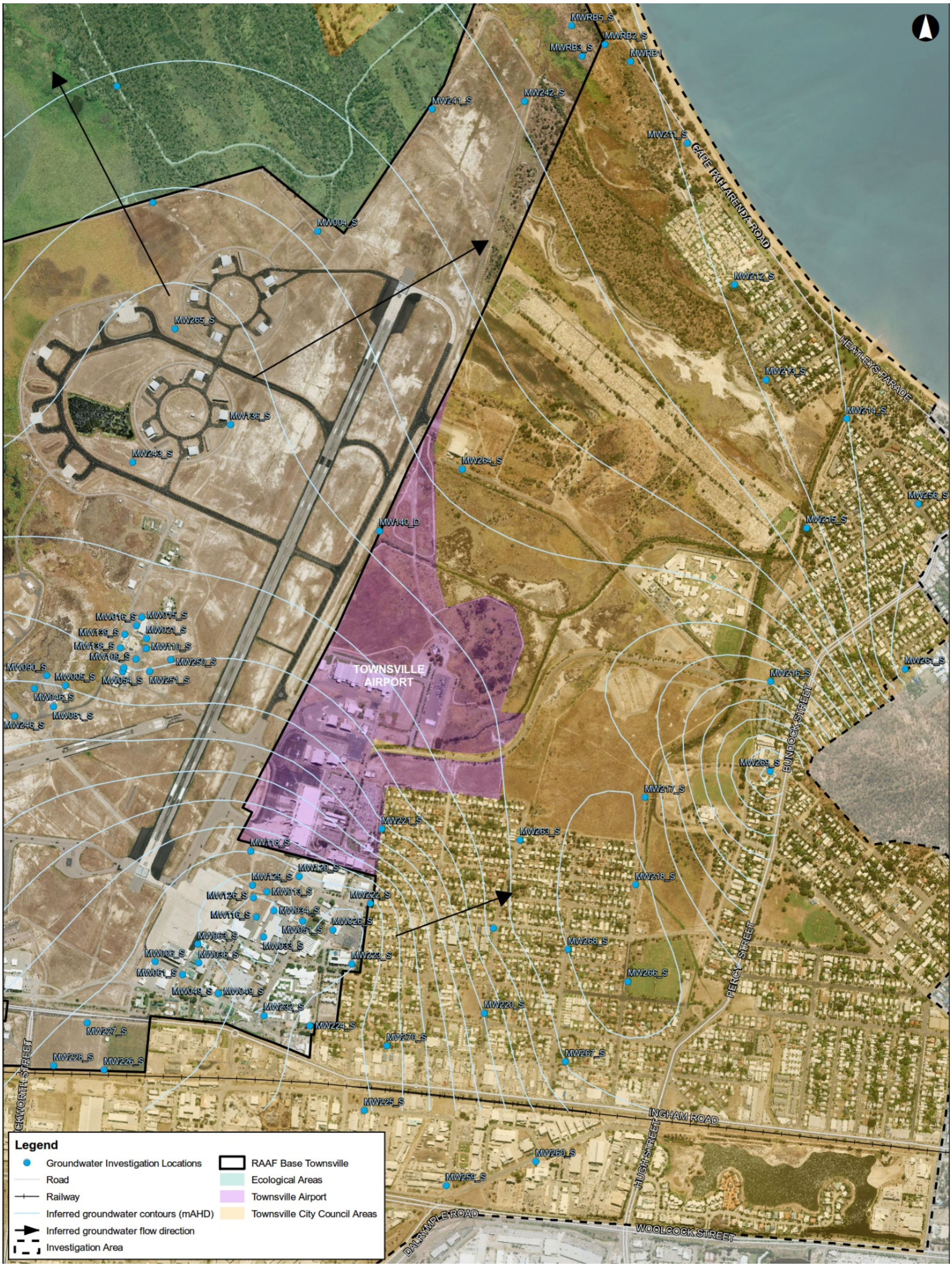


Figure 5.4 Overview of inferred groundwater flow direction from the Base (aerial view). Depicted groundwater contours are representative of the dry season only

In general groundwater flow is considered to observe a similar direction of flow to surface water. With respect to the operational areas of the Base and the identified potential sources of PFAS, groundwater flow direction is considered as follows:

- **North to north-west** – groundwater in the north-west portion of the Base, in the vicinity of the OLA's is expected to flow in a general north and north-westerly direction towards the Town Common and Three Mile Creek and Louisa Creek catchments.
- **North to north-east** – groundwater in the eastern portion of the Base, in the vicinity of the fire station and main runway (Runway 01/19) is expected to flow in a general north and north-easterly direction towards the Townsville Airport, through the residential suburb of Rowes Bay and discharging to the Rowes Bay surface water receptor.
- **East** – groundwater in the south-east portion of the Base, in the vicinity of the Aircraft Washing Facility and Fire Training Ground and Former Cadet Training Ground is expected to flow in a general easterly direction through the residential occupied area of Garbutt, before veering north-east through the residential suburb of Belgian Gardens and eventually discharging into the Rowes Bay surface water receptor.

5.2.3.4 GROUNDWATER QUALITY

With respect to the two aquifers described above in Section 5.2.3.1, groundwater quality is considered as follows:

- **Sandy aquifer**: the average total dissolved solids (TDS) concentrations was reported to be 680 mg/L; considered to be representative of freshwater conditions.
- **Clayey aquifer**: the average TDS was reported to be 12,780 mg/L; considered to be representative of saline conditions.

5.2.3.5 GROUNDWATER USE

A groundwater bore search of the Investigation Area was conducted prior to WSP drilling works using the Department of Natural Resources and Mines (DNRM) groundwater database, accessed via Queensland Globe, which identified 23 registered groundwater bores within the Investigation Area. The registered bores (indicated to be used for irrigation purposes) are located off-Base within the TCC areas except for one registered bore, which is located within the Base itself. Further details of the bore are provided below.

One registered bore is located within the Base (RN166762) within the south-western corner between 5 AVN and Ingham Road. According to the groundwater database, the bore is a monitoring bore only with a depth of 11 m, screened in silt with a standing water level (SWL) of 3.9 m with saline water.

Of note, the evaluation of private bore use and extracted groundwater was addressed as part of the Human Health Risk Assessment (WSP 2018c) and has not been discussed further in the ERA.

6 ECOLOGICAL SETTING

The information presented herein is a summary of desktop information and describes the potential species and environments present within the Investigation Area. This information was utilised to develop the scope of works for biota (aquatic and semi-terrestrial) collection and analysis.

It is noted that the Town Common is infested with weed grasses and is a receiving environment for treated effluent from Mount St John WTP. Whilst it has ecological value, it is a degraded ecosystem due to previous historical farming practices and the current treated effluent discharges into the area from the Mount St John WTP.

6.1 TERRESTRIAL AND SEMI-TERRESTRIAL ENVIRONMENTS

A review of the ecological information contained within AECOM (2015), identified that the Town Common, located north-west of the Base, was grazed from the 1880s to 1970s. Cattle were removed in late 1970s prior to its gazettal as an Environmental Park in 1980. In 1992 it became a Conservation Park under the *Nature Conservation Act*.

The following information is based on WSP's desktop assessment. Coastal vegetation communities and landforms include mangrove forests, tidal mud flats, samphire, freshwater swamps, freshwater lakes, beach ridges, woodland, open forest and vine thickets. This variety of landform and vegetation provides a high diversity of habitats for birds as well as terrestrial and semi-terrestrial invertebrates and mammals.

The Department of Environment and Heritage Protection (DEHP) Regulated Vegetation Management Map (https://qldglobe.information.qld.gov.au/) classifies the Town Common as 'Category B – Remnant vegetation' (areas of remnant vegetation with no differentiation between conservation status) with a section at the centre of the Town Common and at Cape Pallarenda at the north-eastern extent of the Investigation Area, classified as 'Essential Habitat Category A or B'. Areas at the northern end of the Town Common, north and west of the Bohle River, and immediately south of Ingham Road at the southern Base boundary, were categorised as 'A' or 'B' areas comprising a regional ecosystem of concern.

Mangrove forests occur behind the beach ridges of Shelley Beach and along the Bohle River. Sand couch (*Sporobolus virginicus*) is common in the mangroves as well as being a major species of the salt pans along with samphire. From the salt pans, there are large areas of shallow brackish and freshwater swamps dominated by bulkuru sedges (*Eleocharis dulcis*) (Australian Heritage Database, 2018).

Within grassland areas *themeda australis* and *heteropogon triticeus* are predominant and the less saline and swampy areas comprise scattered shrubs. Woodland areas primarily comprise *Melaleuca*, and Moreton Bay ash (*Eucalyptus tessellaris*) is found on beach ridges. Vegetation is diverse along the ridges, changing from open woodland on hills to closed forest in steep gullies and patches of vine thickets. Forest species include *E tessellaris*, *E alba* (popular gum), *E polycarpa* (grey bloodwood) and *E drepanophylla* (grey ironbark). Common vine thicket species are *Cupaniopsis anacardioides*, *Ficus virens* (white dotted fig), *Alphitonia excelsa* (red ash) and *Pleiogynium timorense* (Burdekin plum) (Australian Heritage Database, 2018).

The *Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act)* DoEE Protected Matters Search Tool (PMST) was used to identify ecological Matters of National Environmental Significance (MNES) within a 10 km radius of the Investigation Area. The 10 km radius was determined by selecting an approximate centre-point for the Investigation Area. This buffer distance was chosen to capture the Town Common, Rowes Bay and Cape Pallarenda Conservation Park.

Some examples of terrestrial/semi-terrestrial species recorded within the Investigation Area based on a review of the above-mentioned database searches include:

- Mammals: agile wallaby (*Macropus agilis*), Pale Field Rat (*Rattus tunneyi*), Water Rat (*Hydromys chrysogaster*), Northern Brown Bandicoot (*Isoodon macrourus*) and the common brushtail possum (*Trichosurus vulpecula*).
- Birds: Wandering Whistling-Duck (*Dendrocygna arcuate*), Whistling Kite (*Haliastur sphenurus*), Budgerigar (*Melanopsittacus undulates*), Magpie Goose (*Anseranas semipalmata*), and Australian magpie (*Cracticus tibicen*).
- Invertebrates (including those identified within aquatic environments): Marsh Tiger (*Danaus affinis affinis*), Lesser Wanderer (*Danaus petilia*), mud crab (*Scylla serrata*), banana prawn (*Fenneropenaeus merguiensis*).
- Plants (listed as '*vulnerable*' from the PMST search): Bluegrass (*Dichanthium setosum*), Mt Stuart Ironbark (*Eucalyptus paedoglauca*), Shrubby Bush Pear (*Marsdenia brevifolia*) and *Omphalea celata* (no common name recorded).

We note that use of on-Base areas by ecological receptors is likely to vary considerably based on the degree of activity being undertaken (such as aircraft and vehicle movements), seasonal changes, food availability and migratory movements of bird populations.

In summary, the remnant native vegetation within the Town Common provides a habitat for a range of terrestrial and semi-terrestrial invertebrates, mammals and birds. Due to the diversity of habitats available and the geographic location of the area, species diversity is high in the Town Common (Australian Heritage Database, 2018). It is a major resting and breeding area for birds travelling between Australia and Asia during spring and autumn migrations, and for species with north-south movements across Australia (DoEE Directory of Important Wetlands, 2018).

Of note, the collection of site-specific data for all species listed in the abovementioned groups was not undertaken as part of the ERA due to restrictions on what species can be captured for scientific purposes. However, data was collected for approved semi-terrestrial fauna species by WSP (2018d) as part of the semi-terrestrial sampling and analysis program. This data has been used as a substitute for terrestrial species (where appropriate) and is considered a reasonable approach given their affinity with aquatic habitats which is likely to result in a higher exposure risk to PFAS than terrestrial species. Further details regarding the semi-terrestrial assessment works is provided below.

6.1.1 SEMI-TERRESTRIAL FAUNA DESKTOP ASSESSMENT

A desktop assessment was undertaken in October 2017 (WSP 2017) to assess which semi-terrestrial fauna species may potentially be exposed to PFAS within the Investigation Area. It examined the potential exposure pathway for PFAS in the semi-terrestrial fauna food web to identify the fauna species most at risk of PFAS exposure, bioaccumulation and biomagnification within the Investigation Area. The desktop assessment included a screening process to rule in or out receptors that require further consideration. Species that were already listed as endangered and/or threatened (if identified through database searches), was also a priority consideration in selecting receptors that require further evaluation, as it is expected that these species would be the most 'sensitive' to any negative impact from exposure to PFAS within the Investigation Area.

The details and findings of the desktop assessment that were presented in the report titled: Semi-Terrestrial Fauna Assessment report, November 2017 (WSP, 2017). A summary of this report is provided below.

Database searches utilised to determine the presence of semi-terrestrial species within the investigation Area included the Queensland Department of Science, Information, Technology and Innovation (DSITI) – Wildlife Online; and the PMST (DoEE 2016). A radius of 10 km was selected as the buffer distance to complete database searches.

The Wildlife Online search tool was utilised initially which revealed 561 fauna species having been previously recorded, this included:

- 20 amphibians (frogs)
- 357 birds
- 40 fish
- 14 insects
- 55 mammals
- 74 reptiles
- 1 uncertain (unknown or code pending).

Of the 561 Wildlife Online individual species records, 25 are threatened fauna species listed under the Queensland *Nature Conservation Act 1992* (NC Act) and/or EPBC Act.

The PMST search tool was used to identify ecological Matters of National Environmental Significance (MNES), within the specified 10 km buffer zone. The search identified 37 threatened and 65 migratory fauna species listed under the EPBC Act as follows:

- Threatened fauna:
  - 14 bird species
  - 11 threatened mammal species
  - 8 threatened reptile species; and
  - 4 threatened shark species.
- Migratory fauna:
  - 26 marine species, including:
    - 5 seabirds
    - 7 cetaceans (mammals)
    - 7 fish and sharks; and
    - 7 reptiles
  - 7 terrestrial bird species; and
  - 32 wetland bird species.

The selection process for semi-terrestrial fauna species that require further evaluation of PFAS exposure involved the identification and grouping of fauna species that have an affinity with aquatic habitats and/or are part of the aquatic – terrestrial food web. Aquatic fauna species were excluded, including, fish, sea turtles, sharks, whales and other cetaceans, crabs, bivalves, molluscs, crustaceans and any other aquatic fauna species that cannot survive more than a short period out of water. The level of aquatic habitat dependence and frequency or duration of using aquatic habitats is one of the considering factors in determining a given species risk of PFAS exposure (WSP 2017).

The selection process resulted in the groupings of 180 semi-terrestrial fauna species that have similar aquatic habitat dependence, life cycle requirements and/or feeding behaviour, including:

- 19 amphibians (frogs)
- 154 birds, including:
  - 19 ducks, grebes and geese
  - 5 cormorants and darter
  - 82 waders and shorebirds
  - 27 seabirds
  - 2 reed warblers
  - 10 raptors and owls
  - 8 kingfishers and kookaburras
  - 1 other; and
- 7 mammals.

A species evaluation was completed by WSP (2017) for the identified 180 semi-terrestrial fauna species as part of the desktop assessment, to evaluate the species sensitivity to PFAS exposure within the Investigation Area. Bioaccumulation and biomagnification that may occurring within the local food web via the transfer of PFAS from the lower and middle order trophic levels, to higher-order predatory species was also considered. The outcomes of the species evaluation were utilised to inform the receptors selected for PFAS sampling and analysis (refer Section 6.1.2). Further details regarding the outcomes and the process followed for the species evaluation are provided in the WSP report (WSP 2018d) presented in Appendix D.

6.1.2 KEY FINDINGS OF SEMI-TERRESTRIAL BIOTA SURVEY

The primary aim of the semi-terrestrial biota sampling and analysis program was to investigate the uptake and bioaccumulation of PFAS in local semi-terrestrial biota that inhabit the investigation area, via the collection of lower to middle order food web species. The secondary aim of the investigation was to evaluate the extent and occurrence of PFAS uptake in semi-terrestrial biota within the broader region. The target species that were captured for sampling and analysis included several amphibians and reptiles as outlined below:

- Amphibians:
  - Cane Toad (*Rhinella marina*)
  - Green Tree Frog (*Litoria caerulea*); and
  - Striped Rocketfrog (*Litoria nasuta*).
- Reptiles:
  - Cann's Longnecked Turtle (*Chelodina canni*); and
  - Freshwater Snake (*Tropidonophis mairii*).

Based on the findings of the DSI, semi-terrestrial fauna sampling and subsequent laboratory analysis targeted three locations identified as containing elevated PFAS concentrations, these being Town Common, Rowes Bay Wetland and an area consistent with Louisa Creek Wetland (west of the RAAF Base). Alligator Creek, located approximately 30 km south-east of the RAAF Base was selected as the comparative site.

The target species were captured using a variety of survey methods and further details regarding the field survey sampling methods are presented in the WSP report (2018d) provided in Appendix D.

A total of 84 semi-terrestrial fauna biota samples (comprising a mixture of reptiles and amphibians) were collected in the field and PFOS + PFHxS was detected in semi-terrestrial fauna species sampled at each of the four locations. With the exception of one sample in Rowes Bay, all the samples collected from the three locations within the Investigation Area reported detectable concentrations of PFHxS and/or PFOS, and 29% of samples from the comparative location.

Within amphibians, the cane toad consistently reported higher average concentrations of PFOS + PFHxS at each sampling location, and amphibians from Town Common reported the highest average PFOS + PFHxS concentrations followed by the wetland in Rowes Bay , Louisa Creek Wetland and Alligator Creek. There was however a relatively large standard error associated with data from Rowes Bay Wetland and Town Common, suggesting differences in the reported concentrations may not be statistically significant.

The combined average PFOS + PFHxS concentration reported in amphibians from the Investigation Area was 67 µg/kg and therefore exceeding the adopted assessment criteria (the adopted assessment criteria is discussed further in Section 8.2).

Concentrations of PFOS + PFHxS were not detected within reptiles at the comparative location of Alligator Creek, however results were based on four freshwater snake specimens only as no Canns Longnecked turtles could be caught at this location. The sample size from Town Common and Rowes Bay was >10 reptiles making for a more robust dataset, while only three samples (one freshwater snake and two Canns Longnecked turtles) were able to be collected from Louisa Creek. Within the Investigation Area, the highest concentrations were reported in Town Common, followed by the wetland in Rowes Bay and Louisa Creek Wetland. Concentrations of PFOS + PFHxS in samples of freshwater snake from the Town Common were generally an order of magnitude higher than the Canns Longnecked turtle. The combined average PFOS + PFHxS concentration reported in reptiles from the Investigation Area was 1,152 µg/kg and therefore exceeding the adopted assessment criteria.

Assessment of the concentration of PFOS + PFHxS in two trophic levels, i.e. secondary consumers (amphibians) and tertiary consumers (reptiles), of the semi-terrestrial food web, indicated biomagnification was occurring in the tertiary consumers sampled.

A detailed review of the semi-terrestrial sample results is provided in Section 8.2.3. An evaluation regarding direct toxicity and the potential for bioaccumulation within the species evaluated is provided in Section 11.1.2.

6.2 AQUATIC ENVIRONMENTS

Several aquatic and wetland environments are present in the Investigation Area. A review of previous ecological assessments (AECOM, 2015) and database records demonstrates that the Town Common and Bohle River support a diverse community of commonly occurring aquatic biota and variety of aquatic habitats including freshwater wetlands and waterways, and estuarine wetlands and waterways (supporting mangroves, saltmarsh and claypans).

The following information is based on WSPs desktop assessment and was utilised to develop the scope of works for aquatic biota collection and analysis. The wetlands which are partly situated on-Base as well as the town Common, has been designated a 'Nationally important wetland' (DoEE Directory of Important Wetlands). They form the lower catchment of Louisa Creek which despite being significantly modified retains fish habitat and remnant riverbank native vegetation although the introduced para grass has caused degradation and has increased in prevalence with urbanisation.

Despite being relatively degraded, the wetlands do provide ecological value and are recognised as a waterbird refuge, providing a drought refuge and a breeding and feeding area for large and diverse populations of waterbirds. There is significant seasonal variation in the wetlands, some drying out completely during the dry season. The decrease in water volume has been associated with damming of Ross River (in the 1970s) and construction of the airport which has diverted some of the catchment.

The estuarine reaches of the Town Common and Bohle River, including the on-Base wetlands to the west and south of the OLAs, are mapped as having very high and high aquatic conservation values respectively under the Aquatic Biodiversity Assessment Mapping Method (AquaBAAM) (Rollason and Howell, 2012). The freshwater wetlands are mapped as having high ecological significance and matters of State environmental significance (MSES) under the State Planning Policy (SPP) (DILGP, 2018).

The Town Common and the estuarine reaches of the Bohle River are part of the Bohle River Fish Habitat Area (FHA-027), which is designated 'Management Level B' for its importance to recreational, traditional and commercial fisheries (Department of National Parks, Recreation, Sport and Racing (NPRSR), 2012). The Town Common and Bohle River drain in the southern extent of Halifax Bay, a conservation park zone of the GBRMP.

The lower reaches of the Bohle River are classified as 'Category R – Reef regrowth watercourse vegetation' on the Regulated Vegetation Management Map. The wetlands in the upper reaches of Three Mile Creek between the Base and the former Rowes Bay Landfill are mapped as having high aquatic conservation values under AquaBAAM (DEHP, 2018). The lower reaches of Three Mile Creek are also included in the Bohle River Fish Habitat Area. Portions of the Three Mile Creek and Mundy Creek wetlands are classified 'Category B – Remnant vegetation' on the Regulated Vegetation Management Map, with the banks of the lower reaches classified as 'Category R – Reef regrowth watercourse vegetation'.

Annual rainfall in the Townsville area varies greatly which influences filling of the wetlands and therefore distribution of wetland vegetation varies from year to year. The introduced para grass (which greatly increased in density following livestock removal from the area) dominates sections of wetland environments, while Cumbungi reeds (*Typha* spp.) dominates where water is semi-permanent and are declared an invasive plant which can interfere with water flow and quality (AECOM, 2015). Waterlilies (*Nymphaea*spp.) are the most common of the water plants present within deep water lagoons (Australian Heritage Database, 2018).

The on-Base wetlands support various notable flora species including samphires (*Arthrocnemum leiostachyum*, *A. halocnemoides* and beaded samphire *Salicornia quinqueflora*), sand couch (*Sporobolus virginicus*), salt-water paspalum

(*Paspalum vaginatum*), water lilies (*Nymphaea* spp.), sedges (*Eleocharis* spp.), as well as *Cyperus* spp. and bulkuru sedge (*Eleocharis dulcis*) which both provide an important food source for small birds (DoEE Directory of Important Wetlands).

As indicated in Section 6.1 above, there is significant seasonal migration of waterbirds (some 300 bird species have been recorded in the area), with the area providing habitats for breeding, roosting and feeding (Australian Heritage Database, 2018). It is a major resting and breeding area for birds migrating between Australia and Asia during spring and autumn, as well as the movement of species across Australia. These migratory species and their habitat are subject to bilateral migratory bird agreements with China and Japan (Woodward-Clyde, 1999, referenced in DoEE Directory of Important Wetlands). These migratory species must also be placed on the migratory species list under the EPBC Act.

Examples of aquatic birds recorded in the Investigation Area include Magpie geese (*Anseranus semipalmata*), Brolgas (*Grus rubicundus*), Wandering Whistling-Duck (*Dendrocygna arcuata*), White-browed Crake (*Amaurornis cinerea*) and Little Pied Cormorant (*Phalacrocorax sulcirostris*).

As discussed in the ESP reports (2018a, 2018b and 2018c), mangrove and saltmarsh support a range of invertebrate, birds and fish by providing food and shelter. Seagrass beds occur mainly in Halifax and Cleveland Bay rather than estuarine reaches of the Town Common or Bohle River. The aquatic environments in the Investigation Area provide habitat for a variety of estuarine fish and crustacean species (e.g. barramundi, mangrove jack, mullet, bream, mud crabs and prawns), Dugongs in Cleveland Bay; as well as various species listed in the EPBC Act Protected Matters Search tool (listed as endangered or vulnerable) including six species of marine turtle, eight species of shark and ray, seven species of marine mammal, and the saltwater/estuarine crocodile (*Crocodylus porosus*).

The Town Common and Bohle River are the major aquatic habitats within the Investigation Area, with the lower reaches mapped as estuarine wetlands. The upper reaches of the Bohle River are mapped as freshwater environments. Alligator Creek located approximately 23 km south-east of the Base was selected as a comparative freshwater sampling site for two fish species and one crustacean. (refer Appendix E for ESP reports).

Under the Queensland Environmental Protection (Water) Policy 2009 (EPP (Water)), the environmental values of the estuarine reaches of the Town Common and Bohle River are listed as aquatic ecosystems, human consumption, secondary (Bohle River only) and visual recreation, and cultural and spiritual values. Aquatic flora communities predominantly comprise mangroves and saltmarsh. Halifax, Rowes and Cleveland Bays (including the Town Common and Bohle River) are valued recreational fisheries which include several estuarine, inshore, reef and pelagic fish species.

In summary, the Town Common and the Bohle River support a diverse community of aquatic biota and a variety of aquatic habitats including both freshwater and estuarine wetlands and waterways.

6.2.1 KEY FINDINGS OF AQUATIC BIOTA SURVEYS

Four aquatic biota surveys were completed by ESP with biota sampling and analysis completed in freshwater, estuarine and marine environments targeting areas with known PFAS impacts within the Investigation Area and comparative sites outside the Investigation Area.

During the first survey in July 2017, a variety of sampling methods were utilised depending on the biota type (further details regarding the field survey sampling methods is presented in the ESP report (2018b)). Samples of either fish, crustaceans, bivalves or samphire were collected from ten locations within the Investigation Area and three comparative locations outside the Investigation Area. Analysis of PFAS in liver, flesh, whole organism or plant material was undertaken on a total of 133 biota samples and PFOS and PFHxS were the most widespread PFAS compounds detected.

Approximately 20% of samples from comparative sites reported detectable concentrations of PFHxS and/or PFOS. The highest concentrations of PFOS + PFHxS were reported from biota samples in Bohle River and Town Common and were generally fish species, most commonly detritivores and consumers. The comparative sites were within 10 km of the mouth of the Bohle River and results indicate that elevated concentrations of PFOS + PFHxS (i.e. exceeding adopted screening criteria) generally do not extend to this extent (only two biota samples exceeded screening criteria).

PFOS + PFHxS was reported at higher concentrations within whole and liver samples compared to fish flesh, and in whole crustaceans compared with flesh alone. It was detected amongst all trophic levels in the Town Common and the majority of trophic levels in Bohle River. Concentrations increased in higher trophic levels, however fish detritivores also reported high concentrations. This initial survey did not include large predatory fish however the presence within species such as mullet (a food source for predatory species) indicates PFOS + PFHxS is available to large predatory species.

Subsequent surveys (of estuarine and marine sites from November 2017 to March 2018) which did include large predatory species found that the majority of liver samples (approximately 90%) contained detectable PFOS + PFHxS concentrations. Similarly to other trophic levels, much lower concentrations were found within flesh samples of predatory fish, with approximately 20% of flesh samples containing detectable concentrations of PFOS + PFHxS.

The second survey conducted in November/December 2017 was undertaken within three estuarine impact sites within the Investigation Area and two comparative estuarine sites outside the Investigation Area. Biota types collected included fish (whole, flesh, and liver), crustaceans (flesh and organ), and mangroves. PFOS and PFHxS were again the most widespread PFAS compounds detected and within the impact sites were detected in 76% of fish or crustacean biota samples. PFAS was not detected within any plant samples. At the comparative sites only 8% of all biota samples reported detectable concentrations of PFOS and/or PFHxS.

The highest concentration of PFOS + PFHxS within fish was from liver samples from the Town Common of either consumers or detritivores. Within crustaceans, the highest concentrations of PFOS + PFHxS were from omnivore organ samples collected from Bohle River or the Town Common.

The third aquatic survey comprised analysis of marine biota samples collected from south-west of Magnetic Island, Rowes Bay, Althaus Creek and Bohle River in March 2018. Biota types collected included fish (flesh and liver), crustaceans (flesh and organ), macroalgae and seagrass. Two sites (Bohle River mouth and Rowes Bay) were located within the Investigation Area and three sites represented comparative sites outside the Investigation Area (Magnetic Island (two sites) and Althaus Creek).

PFOS and PFHxS were the most widespread PFAS compounds detected (detected in 46% of all samples, 53% of samples from impact sites, and 36% of samples from comparative sites) and Bohle River reported the majority of elevated PFOS + PFHxS. Of the impact sites, the highest concentrations were detected in liver samples of apex predators (barred queenfish or barramundi) from the Bohle River mouth, with a consumer species (blue catfish) from Rowes Bay also reporting one of the highest concentrations. The highest concentration of PFOS + PFHxS reported was in fact from a comparative site (Althaus Creek mouth) detritivore liver sample of a diamond scale mullet. Mature mullet are known to migrate long distances and so it is possible the exposure may be as a result of time spent in other environments more akin to impact sites.

Detectable concentrations in crustaceans were lower than fish and elevated concentrations were generally reported in omnivore organ samples of blue swimmer crab. Only one crustacean sample from the comparative location at Althaus Creek was below the laboratory LOR.

PFOS and/or PFHxS were not detected within any of the plant samples from impact sites or comparative sites, however 4 µg/kg of PFPeA was detected within one seagrass sample from Magnetic Island (comparative site).

7 PROBLEM IDENTIFICATION

7.1 GENERAL

This section of the ERA provides an overview of the activities conducted at the Base, identified contamination, the primary transport mechanisms that are occurring from identified source areas (i.e. on-site drainage channels) and details the potential receptors selected for evaluation in the ERA.

7.2 ACTIVITIES CONDUCTED AT THE BASE

Activities which are known or likely to have occurred at the Base include:

- training activities (excluding firefighting training with AFFF) within former fire training grounds, fuel storage areas and emergency response (i.e. fuel spills, aircraft accidents)
- routine operation of fire deluge systems, equipment testing and sparging of fire truck tanks at Fuel Farm 2 (NQ0099)
- maintenance of the on-Base fuel farms and aircraft/vehicle maintenance
- maintenance of on-Base underground services
- maintenance of on-Base stormwater drainage channels/systems
- discharges from water treatment plants to off-Base
- accidental discharges and spills from AFFF-containing fire deluge systems in hangars (Buildings 236 and 295) at 5 AVN
- equipment testing and AFFF storage at the 5 AVN wash point (Building 366) and GSE compound
- historical fire training within various areas at the Base including the former fire training grounds (NQ0105, NQ0106, NQ0107 and NQ0054), Pad Brahman and the fire station (NQ0055)
- historical fire training, sparging of fire truck tanks, AFFF spills and storage of PFAS impacted soil at disused Runaway 13/31
- historical fire training by cadets and AFFF discharging to ground at open day demonstrations at the field adjacent to the domestic area
- possible emergency response events adjacent to Runway 07/25 and Runway 01/19; and
- historical discharge of AFFF to ground, during open day demonstrations at the Ingham Road sports fields.

7.3 IDENTIFIED CONTAMINATION

As indicated in Table 3.2, Section 3.4 detectable concentrations of PFAS were identified within soil, groundwater, sediment and surface water samples collected on-Base. Off-Base areas investigated as part of the DSI, reported PFAS impacts within groundwater, surface water and sediment samples; as well as aquatic biota (namely finfish and crustaceans) collected from both estuarine and freshwater catchments, as well as semi-terrestrial biota samples. A detailed data evaluation and screening assessment for on-Base and off-Base areas is provided in Section 8.3 and 8.4.

7.4 PFAS CHEMICALS OF POTENTIAL CONCERN (COPC)

The primary AFFF product use at Defence sites until 2004–2005 was 3M Lightwater™, which is known to contain many PFAS compounds (many of which do not currently have a method for laboratory quantification). The reported analytical results identified the dominant PFAS compounds to be PFOS, PFHxS and to a lesser extend PFOA.

Other PFAS compounds have also been detected less frequently including perfluorohexanoic acid (PFHxA), perfluorobutane sulfonic acid (PFBS), perfluoropentane sulfonic acid (PFPeS), perfluorodecane sulfonic acid (PFDS), perfluorodecanoic acid (PFDA) and 6:2 fluorotelomer sulfonate (6:2 FtS). However most scientific literature reviews and reviews done by the Australian Government have focussed on PFOS, PFHxS and PFOA as these three compounds have been identified to be of most concern from an environmental health viewpoint, based on their toxicity, fate and transport and persistence in the environment.

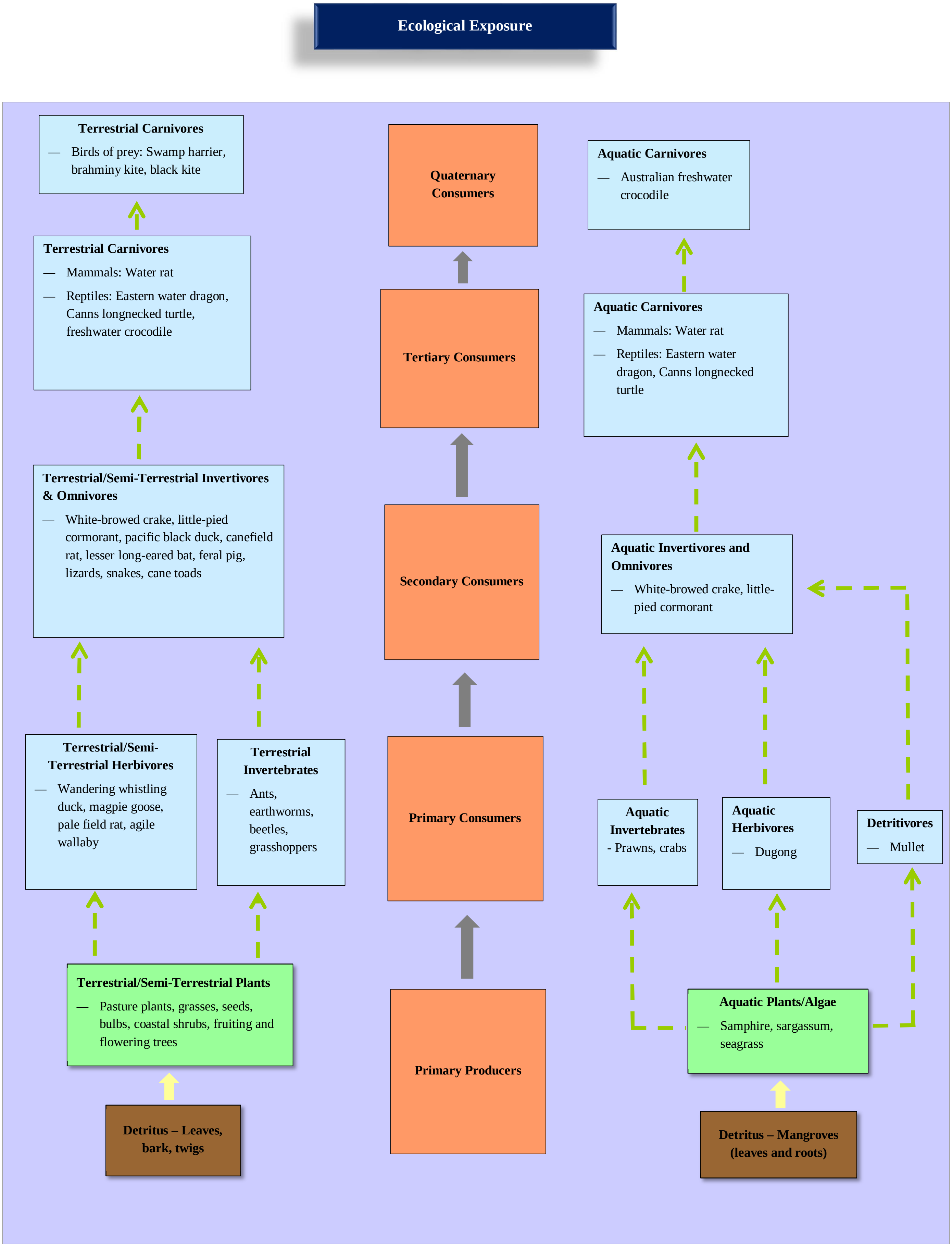
For the assessment of ecological risks, PFOS and PFOA were selected as the PFAS COPC due to an absence of a suitable toxicity reference value to adopt for PFHxS. Further information regarding the presence of other PFAS compounds is provided in Section 10.2.

7.5 CONCEPTUAL SITE MODEL

A pictorial representation of how PFAS moves within the environment (i.e. the interaction between soil, groundwater and surface water) and the various ecological habitats and receptors is provided in Figure 7.1. Ecological exposure pathways are noted to include:

- **Direct exposure** – includes the ingestion and uptake of PFAS contaminated surface water, soil and/or sediments, during the foraging/feeding and/or burrowing behaviours of terrestrial, semi-terrestrial and aquatic species.
- **Indirect exposure:** – this includes the consumption of various organisms (i.e. fish, crustaceans, mammals, reptiles, amphibians, birds or bird eggs), as food sources. PFAS transfer may occur through the food web, to higher order species (i.e. primary-secondary-tertiary consumers) whose diet comprises various wildlife.

Ecological exposure scenarios are discussed further in Section 9.1 of this report.



- Primary producers: exposure occurs via direct pathways via contact with contaminated soil and/or water
- Primary, Secondary, Tertiary and Quaternary Consumers: exposure occurs via indirect pathways via the consumption of plants, water and/or animals

Figure 7.1 PFAS contaminated media and the pathways to ecological exposure

7.6 POTENTIAL TRANSPORT MECHANISMS

Potential transport mechanisms by which PFAS may migrate within and from the site are summarised in Table 7.1 below. Potential transport mechanisms detailed in Table 7.1 are based on a review of data obtained during the DSI.

Table 7.1 Potential contaminant transport mechanisms

<table>
<tr><th>TRANSPORT MECHANISM</th><th>COMMENTS</th><th>OCCURRING (YES/NO)</th></tr>
<tr><td>Leaching from soil to groundwater and transport within groundwater</td><td>PFAS has been reported in groundwater beneath the Base and at off-Base sampling locations.</td><td>Yes – the reported PFAS compounds in groundwater sampled on-Base and off-Base indicates that this transport mechanism is occurring and may act as an ongoing source of PFAS impacts to groundwater.</td></tr>
<tr><td>Leaching from soil and contaminated infrastructure (i.e. concrete) and transport into surface water</td><td>PFAS have been reported in surface water and sediment samples collected from drainage channels and water bodies located on-Base.</td><td>Yes – the reported PFAS compounds in surface water and sediments sampled on-Base and off-Base indicates that this transport mechanism is occurring; and is expected to continue to occur into the future.</td></tr>
<tr><td>Discharge of impacted groundwater to surrounding surface water bodies (i.e. Mundy Creek, Louisa Creek, Town Common and Three Mile Creek)</td><td rowspan="3">PFAS have been detected in sediment and surface water samples collected from Mundy Creek, Louisa Creek, Town Common and Three Mile Creek.</td><td rowspan="3">Yes – the reported presence of PFAS in sediment and surface water sampled from waterways that receive stormwater from the Base indicates that these transport mechanisms are occurring.</td></tr>
<tr><td>Discharge of impacted surface water to surrounding off-site waterways</td></tr>
<tr><td>Suspension of sediment and surficial soil in stormwater deposition in off-site waterways</td></tr>
<tr><td>Bioaccumulation of PFAS in terrestrial, semi-terrestrial and aquatic biota</td><td>Aquatic and semi-terrestrial biota samples (i.e. fish, crustaceans, amphibians, reptiles) collected from off-Base waterways and wetland areas have been reported to contain PFAS above screening criteria.</td><td>Yes – the reported presence of PFAS in biota tissue samples (plant, aquatic invertebrates including crustaceans, and aquatic and semi-terrestrial vertebrates) indicates that the presence of PFAS in environmental media has resulted in the bioaccumulation within local ecological receptors and hence, biomagnification in higher order species.</td></tr>
</table>

7.7 POTENTIAL RECEPTORS

In selecting receptors to evaluate as part of the ERA it is not considered plausible to conduct a risk assessment that evaluates exposure and resultant risk for all ecological species that may be present within the Investigation Area. Hence, a review of the available information regarding habitat, environmental values and sensitive species (i.e. defined as threatened) (refer to Section 6.1) has been undertaken to select a range of representative wildlife species within each trophic level that require further evaluation as part of this ERA.

Potential receptors have been selected to represent tropic levels (i.e. indicator species) for which risks cannot be adequately assessed by comparing reported concentrations in environmental media to a screening benchmark. This is because a screening benchmark does not account for potential risks associated with bioaccumulation and biomagnification. The ERA has relied upon some direct measurements to assess potential risks to lower order animals, as well as a combination of direct and indirect measurements for animals that sit within the middle and upper trophic levels.

Plants and lower order animals (i.e. invertebrates and fish) have been assessed by comparing reported concentrations in environmental media to a screening benchmark (refer Section 11.1). Plants and lower order animals have not been included in quantitative food web modelling, as these species are considered to be more highly and directly exposed to PFAS in environmental media. It is acknowledged that whilst bioaccumulation and biomagnification may be occurring at the lower trophic levels, it is considered that direct measurements are a more appropriate way to assess for this.

The selection of potential receptors to include in quantitative food web modelling have been chosen for trophic levels where no direct measurements could be collected; and for which bioaccumulation and biomagnification of PFAS must be considered, based on dietary intakes from lower trophic levels. The receptors have been selected to represent the body size and dietary composition for a range of species (where possible) within each trophic level. This will enable estimated risks to be linked back to general receptor types within each trophic level, to assess the primary risk drivers for each trophic level.

Representative species from each trophic level have been selected to assist in understanding the potential risks associated with exposure to PFAS. The complete assessment of trophic levels within the Investigation Area was based on the following:

- database searches and survey data for terrestrial and semi-terrestrial flora and fauna species; and
- biota sampling of aquatic and semi-terrestrial fauna species.

The following factors were also considered in selecting potential receptors:

- **Diet:** this includes foods sourced from environments that may have been impacted by PFAS. It was considered important to assess animals within the food web model which consume dietary items likely to have a bioaccumulation of PFAS compounds (i.e. fish). It is also considered important to evaluate species that have a range of dietary habits (i.e. eat foods sourced in different environmental media) to enable (as much as possible) coverage of a broad range of species within each trophic level.
- **Body weight:** the average body weight of a species was considered for two reasons i) there is a direct correlation between the body weight of an animal and food consumption rates and ii) food web modelling is sensitive to body weight. Hence, it was considered important to select receptors which represent a range of species sizes to ensure (for example) that potential risks to different sized birds are adequately addressed.
- **Habitat:** where a species was observed (i.e. via sampling or field survey) or assumed to be present within the Investigation Area, the types of habitat that are present is considered an important component in confirming the types of species that are likely to be present.
- **Sightings:** the sighting of species during ecological surveys and sampling conducted within the Investigation Area was utilised to confirm the presence of species in the relevant habitats.

— **Transitory/migratory species:** special consideration was given to transitory species or species that spend only part of their life cycle within the Investigation Area (i.e. 'fish spawning' in river or predatory birds such as the Swamp Harrier).

A summary of the terrestrial (and semi-terrestrial) and aquatic trophic levels selected for further evaluation either by comparing to screening benchmarks or via quantitative food web modelling is provided in Table 7.2.

Table 7.2 Potential ecological receptors and trophic levels

TROPHIC LEVEL	COMMENT	CONSIDERED FURTHER WITHIN ERA (YES/NO)
Terrestrial and semi-terrestrial		
Assessment via direct comparison to published screening benchmark		
Terrestrial plants	A search of the EPBC search tool for plant species was completed as part of the semi-terrestrial fauna assessment. Four native plant species were identified as 'vulnerable' refer to Section 6.1.	**Yes** – an assessment of terrestrial plants has been undertaken using data collected for aquatic plant species. Analytical results for aquatic plants have been used as a substitute for terrestrial plant data. Given they inhabit aquatic environments their uptake/exposure to PFAS is expected to be higher than terrestrial plant species; and hence is considered a reasonable substitute in the absence of available site-specific terrestrial plant data. Reported results were compared against published terrestrial screening benchmarks. Refer to Section 11.1.1.
Terrestrial invertebrates	This includes earthworms, insects and other invertebrates that may live in the active layer of soil in terrestrial environments. Further detail on the relevant soil depth applicable to this environment is provided in Section 8.2.1.	**Yes** – an assessment of terrestrial invertebrates was investigated and compared against published screening benchmarks. In the absence of site-specific data, analytical results for earthworm data collected from other Defence properties (i.e. AECOM 2016) was used as a substitute. Refer to Section 11.1.1 for further details.
Herbivorous terrestrial mammals	This includes mammals identified during database searches that primarily inhabit terrestrial or semi-terrestrial environments, including burrowing mammals.	**Yes** – a quantitative assessment was undertaken utilising rabbit tissue from AECOM (2018), as a substitute for site-specific data.
Herbivorous arboreal mammals	Arboreal mammals spend most their time in the tree canopy. Hence, their diet consists mainly leaves, shoots, nectar and pollen.	**No** – this trophic level is considered to have a lower exposure compared to terrestrial mammals and therefore have not been considered further in the ERA.

TROPHIC LEVEL	COMMENT	CONSIDERED FURTHER WITHIN ERA (YES/NO)
Invertivorous/omnivorous arboreal mammals	Arboreal mammals spend most their time in the tree canopy. Hence, their diet consists of flying insects and invertebrates which can be found beneath the bark of trees.	**No** – these mammals are considered to have a lower exposure compared to terrestrial mammals and therefore have not been considered further in the ERA.
Assessment via quantitative food web modelling		
Herbivorous terrestrial (and semi-aquatic) birds	This group feeds primarily on grass, seeds, shoots, pollen and nectar. Included in this group are semi-aquatic bird species which graze on land and on aquatic plants.	**Yes** – An evaluation of herbivorous birds has been undertaken via the identified semi-aquatic bird species as per the semi-terrestrial fauna assessment (WSP 2018d). The semi-aquatic bird species are potentially exposed via multiple pathways given they can graze on both terrestrial and aquatic plants and are thus considered to experience a higher exposure to any PFAS present. The evaluation of exposure risks to birds has been undertaken via quantitative food web modelling. Refer to Section 11.2 for further details.
Invertivorous/omnivorous terrestrial and semi-terrestrial mammals	This includes mammals that feed on terrestrial invertebrates and plant matter collected from surface soils.	**Yes** – these mammals are potentially exposed via multiple pathways and have therefore been evaluated via quantitative modelling. Refer to Section 11.2 for further details.
Invertivorous/omnivorous terrestrial (and semi-aquatic) birds	This bird group is considered to feed on terrestrial invertebrates and plant matter which are collected from surface soils.	**Yes** – these birds are potentially exposed via multiple pathways, and therefore have been evaluated via quantitative modelling. Refer to Section 11.2 for further details.
Predatory terrestrial and semi-terrestrial mammals	This includes mammals, birds and reptiles that prey on smaller mammals, fish, amphibians and sometimes insects. These groups may be exposed to trophic level transfer of PFAS (i.e. biomagnification).	**Yes** – biomagnification is potentially occurring in this trophic level for the purposes of conducting the ERA. Potential risks to these receptors has been evaluated via quantitative food web modelling. Refer to Section 11.2 for further details.
Predatory terrestrial and semi-terrestrial reptiles		
Predatory terrestrial birds		
Aquatic: Estuarine, freshwater and marine		
Assessment via direct comparison to published screening benchmark		
Aquatic plants	This group includes aquatic plants and algae.	**Yes** – direct toxicity to aquatic plants was assessed by comparison of surface water concentrations against aquatic screening benchmarks and available plant tissue data collected as part of the aquatic biota sampling events. Refer to Section 11.1 for further details.
Aquatic invertebrates	This includes benthic invertebrates and bottom dwelling filter feeders.	**Yes** – direct toxicity to aquatic invertebrates was assessed by comparison against aquatic screening benchmarks. Refer to Section 11.1.2 for further details.

TROPHIC LEVEL	COMMENT	CONSIDERED FURTHER WITHIN ERA (YES/NO)
Herbivorous aquatic birds	This group includes aquatic and semi-aquatic birds that feed primarily on aquatic plants and algae.	**Yes** – this trophic level has been considered via quantitative food web modelling via the terrestrial/semi-terrestrial food web, based on the identification of semi-aquatic bird species selected for assessment within this trophic level. Refer to Table 7.3 for further details.
Aquatic vertebrates	This includes amphibians and various secondary and tertiary consumer fish species.	**Yes** – direct toxicity to these receptors was assessed via the comparison of aquatic biota tissue data. To evaluate potential exposure to herbivorous aquatic vertebrates, omnivorous fish and crustacean data was compared to relevant screening benchmarks. Refer to Section 11.1.2 for further details.
Invertivorous/omnivorous aquatic organisms	This includes both invertebrate and vertebrate species.	**Yes** – direct toxicity to these receptors has been assessed via comparison of both crustacean data (to represent invertebrates) and fish tissue data, to adopted screening benchmarks. Refer to Section 11.1.2 for further details.
Carnivorous aquatic vertebrates	This includes benthic and pelagic fish species.	**Yes** – direct toxicity to these receptors has been assessed via the comparison of fish tissue data for available predatory fish species and environmental media (i.e. sediments) to adopted screening benchmarks. Refer to Section 11.1.2 for further details.
Assessment via quantitative food web modelling		
Aquatic herbivores	This includes some mammals (i.e. Dugong) and turtle species that only consume aquatic plants and algae	**Yes** – Potential intakes of PFAS from diet have been quantitatively modelled. Refer to Section 11.2 for further details.
Invertivorous/omnivorous aquatic birds	This includes bird species that consume a combination of aquatic invertebrates and aquatic plants/algae.	**Yes** –Potential intakes of PFAS from both diet and environmental media (i.e. sediments) have been quantitatively modelled. Refer to Section 11.2 for further details.
Predatory aquatic birds	This includes aquatic species whose primary diet is fish and other aquatic vertebrates/invertebrates.	**Yes** – potential intakes of PFAS from both diet and environmental media (i.e. sediments) have been quantitatively modelled. Refer to Section 11.2 for further details.
Predatory aquatic mammals		
Predatory aquatic reptiles		

7.7.1 TERRESTRIAL AND SEMI-TERRESTRIAL RECEPTORS SELECTED FOR QUANTITATIVE MODELLING

As indicated in Table 7.2 above, the selected trophic levels and species for terrestrial and semi-terrestrial receptors that were evaluated via food web modelling are:

- herbivorous mammals
- invertivorous/omnivorous mammals
- herbivorous birds
- invertivorous/omnivorous birds
- predatory mammals
- predatory birds; and
- predatory reptiles.

For the selected herbivorous, invertivorous/omnivorous birds; as well as the predatory mammal and reptile species, the focus of quantitative assessment was on species that have an affinity with aquatic environments and/or are part of the aquatic-terrestrial food web. Semi-terrestrial species were selected for these trophic levels as their affinity with aquatic habitats is likely to result in a higher exposure risk to PFAS, than terrestrial species alone.

A summary of the species assessed within each trophic level as well as information on bodyweight, diet and habitat has been summarised below in Table 7.3.

Table 7.3 Terrestrial and semi-terrestrial receptors of concern – adopted body weight, diet and habitats

COMMON NAME (SPECIES NAME)	BODY WEIGHT (kg)	DIET AND HABITAT	PRESENCE
Herbivorous mammals			
Pale field rat (*Rattus tunneyi*)	0.08(1)	The Pale Field Rat occurs in grasslands in northern Australia and east coast of Queensland, with their distribution declining in other areas due to introduced species and habitat change. Their habitat comprises grassy or tussocky open forest, cultivated pasture, pine plantations and canefields (1). The diet consists of roots, grass, stems and seeds (2).	Common. Observed during semi-terrestrial fauna survey
Agile Wallaby (*Macropus agilis*)	15 (female) 27 (male)(3) 21 (average)	The Agile Wallaby is found in coastal and tropical areas of Australia, in woodlands, coastal areas and open forests. Their preferred habitat is flood plains, moving to cliffs and other higher ground during periods of inundation(3). The Agile Wallaby feeds on grasses, legumes, fallen leaves, fruits and flowers. During dry periods they may also dig into soil for moisture-rich roots(3,4).	Abundant within the Town Common
Invertivorous and omnivorous mammals			
Canefield Rat (*Rattus sordidus*)	0.25(5)	The Canefield rat occurs widely in coastal areas of north-eastern Australia and is found mostly in canefields, grasslands and often around swamps or grassy verges of closed forests(5,6). Diet comprises sugar cane, grass seeds and insects.	Abundant within the Town Common

COMMON NAME (SPECIES NAME)	BODY WEIGHT (kg)	DIET AND HABITAT	PRESENCE
Lesser Long-eared Bat (*Nyctophilus geoffroyi*)	0.006 – 0.010[7]	The Lesser Long-eared Bat is one of the most widespread bats endemic to Australia due to its great adaptability. It lives in deserts, tropical to alpine woodlands, mangroves, agricultural land, urban areas, wet to dry sclerophyll forests and rain forests[8]. The diet of the Lesser Long-eared Bat mainly comprises grasshoppers, crickets and moths. In addition, they also eat lacewings, beetles, flies, cricket nymphs, cockroaches and spiders[8].	Recorded within locality (10 km search area as per desktop fauna assessment, WSP 2018d)
Herbivorous Birds			
Wandering Whistling-Duck (*Dendrocygna arcuata*)	0.75[9]	The Wandering Whistling Duck found in northern and eastern Australia prefers deep-vegetated lagoons and swamps, flooded grasslands, pastures, and irrigated lands[10]. It feeds almost entirely on aquatic vegetation and seeds, and occasionally on young grass, the bulbs of rushes and other herbage, insects and other small aquatic animals[10].	Recorded within locality (10 km search area as per desktop fauna assessment, WSP 2018d)
Magpie Goose (*Anseranas semipalmata*)	2–3 [11]	The Magpie Goose is widespread throughout coastal northern and eastern Australia. It occurs in floodplains, swamps and wet grasslands[12]. Magpie geese eat mainly swamp grass seeds, blades of dry grasses, and bulbs of spike-rush. They also eat large quantities of wild rice. During the dry season, magpie geese must rely on roots and bulbs as their primary source of food. During the wet season, they can switch to grass as their main food[11].	Abundant within the Town Common
Invertivorous & Omnivorous Birds			
White-browed Crake (*Amaurornis cinerea*) *NB: this species has been used to assess exposure via both terrestrial/semi-terrestrial and aquatic pathways*	0.04–0.063[13] 0.052 (average)	The White-browed Crake can be found in well vegetated coastal and terrestrial wetlands, both freshwater and saline[13,14]. The White-browed Crake feeds on earthworms, slugs, leeches, insects, water spiders, frog spawn and small fish. They also feed on seeds and leaves of aquatic plants[13,14].	Recorded within locality (10 km search area as per desktop fauna assessment, WSP 2018d)

COMMON NAME (SPECIES NAME)	BODY WEIGHT (kg)	DIET AND HABITAT	PRESENCE
Little Pied Cormorant (*Phalacrocorax sulcirostris*) *NB: this species has been used to assess exposure via both terrestrial/semi-terrestrial and aquatic pathways*	0.49–0.9[15] 0.7 (average)	Sometimes Little Pied Cormorants occur in sheltered bays and inlets, but they are more common at terrestrial wetlands, including artificial wetlands as well as a variety of natural ones[16]. Although Little Pied Cormorants will catch fish, more often they take freshwater crayfish and other crustaceans which are captured during brief dives beneath the water. The prey is brought to the surface or back to the nearby bank, where the claws of the crayfish are shaken off before its body is eaten[16].	Recorded within locality (10 km search area as per desktop fauna assessment, WSP 2018d)
Pacific Black Duck (*Anas superciliosa*)	1.025 (female) – 1.114 (male)[17] 1.07 (average)	The Pacific Black Duck is found in all but the most arid regions of Australia and it can be found in all types of water, from isolated forest pools to tidal mudflats[18]. The Pacific Black Duck is mainly vegetarian, feeding on seeds of aquatic plants. This diet is supplemented with small crustaceans, molluscs and aquatic insects[18].	Recorded within locality (10 km search area as per desktop fauna assessment, WSP 2018d)
Predatory Mammals			
Water Rat (*Hydromys chrysogaster*) *NB: this species has been used to assess exposure via both terrestrial/semi-terrestrial and aquatic pathways*	0.34–1.28[19] 0.81 (average)	The water rat is a semi-terrestrial mammal that occurs in permanent fresh or brackish water and can also be found in marine environments, including coastal mangroves. The Water Rat feeds on fish, crustaceans, shellfish, small birds, eggs, mammals, frogs and reptiles[19].	Recorded within locality (10 km search area as per desktop fauna assessment, WSP 2018d) but not abundant
Predatory Reptiles			
Eastern Water Dragon (*Intellagama lesuerii*) *NB: this species has been used to assess exposure via both terrestrial/semi-terrestrial and aquatic pathways*	0.58–0.70[20] 0.64 (average)	The Eastern Water Dragon occurs in tropical rainforest, riparian forests/woodlands with tree cover and basking sites in association with flowing streams[20]. The diet of the Eastern Water Dragon includes small reptiles, worms, frogs, insects, vegetation, fruit, small mammals, crustaceans, molluscs, crabs and algae[20].	Recorded within locality (10 km search area as per desktop fauna assessment, WSP 2018d)

COMMON NAME (SPECIES NAME)	BODY WEIGHT (kg)	DIET AND HABITAT	PRESENCE
Freshwater Snake (*Tropidonophis mairii*) *NB: this semi-terrestrial specie has been used to evaluate exposure via aquatic pathways*	0.25[21]	The freshwater snake (also known as Keelback) lives in well-watered areas including creeks and swamps but can also be found in eucalypt forests, heaths, pastures, parks and suburban gardens[22]. The freshwater snake feeds on fish, frogs, reptile eggs and mammals[22].	Common. Target species sampled during the semi-terrestrial fauna survey
Canns Longnecked Turtle (*Chelodina canni*) *NB: this species has been used to assess exposure via both terrestrial/semi-terrestrial and aquatic pathways*	0.602 (average)[23]	The Canns Longnecked turtle occurs in rivers, lagoons and swamps. The diet of the Canns Longnecked turtle includes small aquatic animals such as fish, tadpoles, frogs and crayfish[23].	Abundant within the Town Common. Target species sampled during the semi-terrestrial fauna survey
Australian Freshwater Crocodile (*Crocodylus johnstoni*) *NB: this species has been used to assess exposure via both terrestrial/semi-terrestrial and aquatic pathways*	70–100 (male)[24] 40 (female)[24] 55 (average)	The Australian Freshwater Crocodile inhabit various freshwater environments including rivers, creeks, pools, billabongs, lagoons and swamps. They may also shelter in burrows among the roots of trees fringing the water bodies they inhabit. Freshwater Crocodiles can also occur in brackish waters up to ~24% salinity (seawater is 35%)[24]. Freshwater Crocodiles will eat a variety of invertebrate and vertebrate prey, including crustaceans, insects, spiders, fishes, frogs, turtles, lizards, snakes, birds and mammals. Insects (both aquatic and terrestrial) appear to be the most common food item, followed by fish[24]. Larger crocodiles tend to eat larger prey items. However, the average size of prey for all Freshwater Crocodiles is generally small (mostly less than $2cm^2$)[24]. The Freshwater Crocodile has been selected to evaluate potential risks to larger predatory reptiles.	Recorded within locality (10 km search area as per desktop fauna assessment, WSP 2018d)
Predatory Birds			
Swamp Harrier (*Circus approximans*)	0.74 (average)[25]	The Swamp Harrier is often found near fresh or saltwater wetlands in tropical regions during summer[26]. Swamp Harriers hunt for birds and eggs, large insects, frogs, reptiles and small mammals up to the size of hares or rabbits[26].	Recorded within locality (10 km search area as per desktop fauna assessment, WSP 2018d)

COMMON NAME (SPECIES NAME)	BODY WEIGHT (kg)	DIET AND HABITAT	PRESENCE
Brahminy Kite (*Haliastur indus*)	0.53 (average)[27]	The Brahminy Kite is a resident in mangrove swamps and estuaries. It is sometimes seen over forests and along rivers[27]. The Brahminy Kite feeds on fish, crustaceans, insects and carrion (dead animals)[27].	Recorded within locality (10 km search area as per desktop fauna assessment, WSP 2018d)
Black Kite (*Milvus migrans*)	0.54 (average)[28]	The Black Kite's range covers most of the Australian mainland and is found in open plains, timbered watercourses, rubbish dumps, and outback towns [28]. They predate all manner of small vertebrates, many types of invertebrates, and will take carrion[29].	Recorded within locality (10 km search area as per desktop fauna assessment, WSP 2018d)

(1) Queensland Museum: http://www.qm.qld.gov.au/Find+out+about/Animals+of+Queensland/Mammals/Common+mammals+of+south-east+Queensland/Rats+and+Mice/Pale+Field+Rat#.Wp3yauhua70
(2) Threatened Species of Northern Territory: https://nt.gov.au/__data/assets/pdf_file/0020/205517/pale-field-rat.pdf
(3) The Animal Facts: http://theanimalfacts.com/mammals/agile-wallaby/
(4) Animal Diversity Web: https://animaldiversity.org/accounts/Macropus_agilis/
(5) Threatened Species of the Northern Territory: https://nt.gov.au/__data/assets/pdf_file/0007/205477/canefield-rat.pdf
(6) The IUCN Red List of Threatened Species: http://www.iucnredlist.org/details/19363/0
(7) Biodiversity of the Western Volcanic Plains: http://bwvp.ecolinc.vic.edu.au/fieldguide/fauna/lesser-long-eared-bat#details
(8) Wikipedia: https://en.wikipedia.org/wiki/Lesser_long-eared_bat
(9) Wikipedia: https://en.wikipedia.org/wiki/Wandering_whistling_duck
(10) Birds in Backyards: http://www.birdsinbackyards.net/species/Dendrocygna-arcuata
(11) Animal Diversity Web: https://animaldiversity.org/accounts/Anseranas_semipalmata/
(12) Birds in Backyards: http://www.birdsinbackyards.net/species/Anseranas-semipalmata
(13) Handbook of the Birds of the World (HBW) Alive: https://www.hbw.com/species/white-browed-crake-amaurornis-cinerea
(14) ICUN Red List: http://www.iucnredlist.org/details/full/22692723/0
(15) Second Opinion Doctor: http://www.second-opinion-doc.com/bird-facts-little-pied-cormorant.html
(16) Birdlife Australia: http://www.birdlife.org.au/bird-profile/little-pied-cormorant
(17) Oiseaux-Birds: http://www.oiseaux-birds.com/card-pacific-black-duck.html
(18) Birdlife Australia: http://www.birdlife.org.au/bird-profile/pacific-black-duck
(19) Australian Museum: https://australianmuseum.net.au/water-rat
(20) Australian Museum: https://australianmuseum.net.au/uploads/documents/25515/water%20dragon%20husbandry%20guidelines%20chris%20hosking.pdf
(21) Brown, GP., Shine, R. (2005) Female Phenotype, Life History, and Reproductive Success in Free-Ranging Snakes (Tropidonophis mairii), Ecology, 86(10) pp. 2763-2770.
(22) Queensland Museum: http://www.qm.qld.gov.au/Find+out+about/Animals+of+Queensland/Reptiles/Snakes/Common+and+dangerous+species/Freshwater+Snake+Keelback+Snake#.WmlIxeQUky8
(23) Kennett et al (2009), Chelodina longicollis (Shaw 1794) - Eastern Long-Necked Turtle, Common Long-Necked Turtle, Common Snake-Necked Turtle.
(24) Australian Museum: https://australianmuseum.net.au/freshwater-crocodile
(25) Birds in Backyards: http://www.birdsinbackyards.net/species/Circus-approximans
(26) Birdlife Australia: http://birdlife.org.au/bird-profile/Swamp-Harrier
(27) Birds in backyards: http://www.birdsinbackyards.net/species/Haliastur-indus
(28) Birds in backyards: http://www.birdsinbackyards.net/species/Milvus-migrans
(29) Birds SA: https://birdssa.asn.au/birddirectory/black-kite/

7.7.2 AQUATIC (ESTUARINE AND FRESHWATER)

As indicated in Table 7.2 above, the selected trophic levels and species for aquatic receptors that were evaluated via food web modelling are:

- herbivorous aquatic mammals
- invertivorous/omnivorous aquatic birds (also assessed via the terrestrial and semi-terrestrial food web, given the relationship between the semi-terrestrial and aquatic environments)
- predatory aquatic birds
- predatory aquatic mammals; and
- predatory aquatic reptiles.

Of note, herbivorous aquatic birds have not been included in the above list, as the assessment of semi-aquatic invertivorous and omnivorous birds were considered appropriately conservative for assessment of herbivorous birds.

The behaviour of invertivorous/omnivorous and predatory bird species considered likely to inhabit the Investigation Area, is such, that exposure is likely to occur via both terrestrial/semi-terrestrial, freshwater and estuarine pathways. Therefore, receptors for terrestrial (semi-terrestrial) and estuarine environments were considered representative of freshwater environments.

The evaluation of exposure risks to predatory mammals and reptiles has also focussed on species that have an affinity with aquatic habitats and/or are part of the aquatic-terrestrial food web, as this is likely to result in a higher exposure risk to PFAS, than terrestrial species. Hence, the predatory mammal and reptile species adopted to evaluate exposure via the terrestrial/semi-terrestrial food web (refer to Table 7.3 above) have been used to evaluate exposure via aquatic pathways.

Table 7.4 summarises information regarding the body weight, diet and habitat for the identified aquatic receptors within the Investigation Area.

Table 7.4 Aquatic (estuarine and freshwater) receptors of concern – adopted body weight, diet and habitats (1)

COMMON NAME (SPECIES NAME)	BODY WEIGHT (kg)	DIET AND HABITAT	PRESENCE
Herbivorous mammals			
Dugong (*Dugong dugon*)	420(2)	The Dugong is a large herbivorous marine mammal that can be found along the Queensland coast. They prefer wide, shallow, protected bays and mangrove channels and the inside edge of large inshore islands. These areas coincide with seagrass beds(2). They also use deep-water habitats. Large numbers have been sighted in water more than 10 m deep in several areas including the Torres Strait, the northern Great Barrier Reef region, and Hervey Bay in southeast Queensland(2). Dugongs feed almost exclusively on seagrass, a flowering plant found in shallow water areas. An adult will eat about 7% of their body weight in seagrass each day. They will also feed on macro-invertebrates such as sea squirts(2).	Recorded within locality (i.e. Cleveland Bay)

COMMON NAME (SPECIES NAME)	BODY WEIGHT (kg)	DIET AND HABITAT	PRESENCE
Invertivorous and omnivorous birds			
White-browed Crake (*Amaurornis cinerea*) *NB: this species has been used to assess exposure via both terrestrial/semi-terrestrial and aquatic pathways*	0.04–0.063[(3)] 0.052 (average)	The White-browed Crake is a semi-aquatic bird species that is commonly found in well vegetated coastal and terrestrial wetlands, both freshwater and saline. The White-browed Crake feeds on earthworms, slugs, leeches, insects, water spiders, frog spawn, small fish, seeds and leaves of aquatic plants[(3,4)].	Recorded within locality (10 km search area as per desktop fauna assessment, WSP 2018d)
Little Pied Cormorant (*Phalacrocorax sulcirostris*) *NB: this species has been used to assess exposure via both terrestrial/semi-terrestrial and aquatic pathways*	0.49–0.9[(5)] 0.7 (average)	The Little Pied Cormorant is found throughout Australia within both fresh and salt water habitats[(5]. The Little Pied Cormorant feeds on a variety of aquatic animals, from insects to fish, freshwater yabbies and crustaceans[(6)].	Recorded within locality (10 km search area as per desktop fauna assessment, WSP 2018d)
Predatory birds			
Eastern Great Egret (*Ardea modesta*)	0.7–1.2[(7)]	The Eastern Great Egret is a migratory species that has been reported to inhabit a range of wetland environments, both inland (freshwater) and coastal (marine/estuarine) wetlands, as well as swamps, marshes and river margins. It is most often found in shallower waters of its environment[(7)]. The Eastern Great Egret feeds mainly on fish and a variety of animals, including insects, crustaceans, molluscs, frogs, lizards, snakes and small birds and mammals[(7)].	Recorded within locality (10 km search area as per desktop fauna assessment, WSP 2018d)
Little Black Cormorant (*Phalacrocorax sulcirostris*)	0.52–1.21[(8)] 0.865 (average)	The Little Black Cormorant is strongly aquatic, is mainly found in freshwater wetlands, but will sometimes be found on sheltered coastal waters, and can use relatively small, deep water bodies[(9)]. The Little Black Cormorant catches its prey underwater and feeds mainly on fish, but also crustaceans and aquatic insects[(9)].	Recorded within locality (10 km search area as per desktop fauna assessment, WSP 2018d)

COMMON NAME (SPECIES NAME)	BODY WEIGHT (kg)	DIET AND HABITAT	PRESENCE
Predatory reptiles			
Freshwater Snake (*Tropidonophis mairii*) *NB: this semi-terrestrial specie has been used to evaluate exposure via aquatic pathways*	0.25[10]	The freshwater snake (also known as Keelback) lives in well-watered areas including creeks and swamps but can also be found in eucalypt forests, heaths, pastures, parks and suburban gardens[10,11]. The freshwater snake feeds on fish, frogs, reptile eggs and mammals[10,11].	Common. Target species sampled during the semi-terrestrial fauna survey
Eastern Water Dragon (*Intellagama lesuerii*) *NB: this species has been used to assess exposure via both terrestrial/semi-terrestrial and aquatic pathways*	0.58–0.70[12] 0.64 (average)	The Eastern Water Dragon occurs in tropical rainforest, riparian forests/woodlands with tree cover and basking sites in association with flowing streams[12]. The diet of the Eastern Water Dragon includes small reptiles, worms, frogs, insects, vegetation, fruit, small mammals, crustaceans, molluscs, crabs and algae[12].	Recorded within locality (10 km search area as per desktop fauna assessment, WSP 2018d)
Canns Longnecked Turtle (*Chelodina canni*) *NB: this species has been used to assess exposure via both terrestrial/semi-terrestrial and aquatic pathways*	0.602 (average)[13]	The Canns Longnecked turtle occurs in rivers, lagoons and swamps. The diet of the Canns Longnecked turtle includes small aquatic animals such as fish, tadpoles, frogs and crayfish[13].	Abundant within the Town Common. Target species sampled during the semi-terrestrial fauna survey

COMMON NAME (SPECIES NAME)	BODY WEIGHT (kg)	DIET AND HABITAT	PRESENCE
Australian Freshwater Crocodile (*Crocodylus johnstoni*) *NB: this species has been used to assess exposure via both terrestrial/semi-terrestrial and aquatic pathways*	70–100 (male)[14] 40 (female)[14] 55 (average)	The Australian Freshwater Crocodile inhabit various freshwater environments including rivers, creeks, pools, billabongs, lagoons and swamps. They may also shelter in burrows among the roots of trees fringing the water bodies they inhabit. Freshwater Crocodiles can also occur in brackish waters up to ~24% salinity (seawater is 35%)[14] Freshwater Crocodiles will eat a variety of invertebrate and vertebrate prey, including crustaceans, insects, spiders, fishes, frogs, turtles, lizards, snakes, birds and mammals. Insects (both aquatic and terrestrial) appear to be the most common food item, followed by fish[14]. Larger crocodiles tend to eat larger prey items. However, the average size of prey for all Freshwater Crocodiles is generally small (mostly less than $2cm^2$)[14]. The Freshwater Crocodile has been selected to evaluate potential risks to larger predatory reptiles.	Recorded within locality (10 km search area as per desktop fauna assessment, WSP 2018d)
Predatory mammals			
Water Rat (*Hydromys chrysogaster*) *NB: this species has been used to assess exposure via both terrestrial/semi-terrestrial and aquatic pathways*	0.34–1.28[15]	The water rat is a semi-terrestrial mammal that occurs in permanent fresh or brackish water and can also be found in marine environments, including coastal mangroves. The Water Rat feeds on fish, crustaceans, shellfish, small birds, eggs, mammals, frogs and reptiles[15].	Recorded within locality (10 km search area as per desktop fauna assessment, WSP 2018d) but not abundant
Australian Snubfin Dolphin (*Orcaella brevirostris*)	114–133[16] 124 (average)[16]	The Australian Snubfin Dolphin has been recorded across northern Australia (QLD, NT and WA) where it inhabits riverine, estuarine and coastal waters[17]. The Australian Snubfin Dolphin is a generalist feeder, taking food from the bottom of the ocean and the water column. Its diet consists primarily of fish, but includes cephalopods (such as squid and octopus) and crustaceans (such as prawns and crabs)[17].	The presence of the Australian Snubfin Dolphin has not been confirmed within the Investigation Area. However, it has been selected to evaluate potential risks to tertiary consumers.

Notes for Table 7.4 above

(1) Some data and information collected for estuarine environments has been used to represent freshwater environments.

(2) Queensland Government, Department of Environment and Heritage Protection: https://www.ehp.qld.gov.au/wildlife/animals-az/dugong.html

(3) Handbook of the Birds of the World (HBW) Alive: https://www.hbw.com/species/white-browed-crake-amaurornis-cinerea

(4) ICUN Red List: http://www.iucnredlist.org/details/full/22692723/0

(5) Second Opinion Doctor: http://www.second-opinion-doc.com/bird-facts-little-pied-cormorant.html

(6) Birdlife Australia: http://www.birdlife.org.au/bird-profile/little-pied-cormorant

(7) Department of Environment and Energy – Species Profile and Threats Database: http://www.environment.gov.au/cgi-bin/sprat/public/publicspecies.pl?taxon_id=82410

(8) Wildscreen Arkive: https://www.arkive.org/little-black-cormorant/phalacrocorax-sulcirostris/

(9) Birds in Backyards: http://www.birdsinbackyards.net/species/Phalacrocorax-sulcirostris and Birdlife Australia: http://birdlife.org.au/bird-profile/Little-Black-Cormorant

(10) Brown, GP., Shine, R. (2005) *Female Phenotype, Life History, and Reproductive Success in Free-Ranging Snakes (*Tropidonophis mairii*),* Ecology, 86(10) pp. 2763-2770.

(11) Queensland Museum: http://www.qm.qld.gov.au/Find+out+about/Animals+of+Queensland/Reptiles/Snakes/Common+and+dangerous+species/Freshwater+Snake+Keelback+Snake#.WmlIxeQUky8

(12) Australian Museum: https://australianmuseum.net.au/uploads/documents/25515/water%20dragon%20husbandry%20guidelines%20chris%20hosking.pdf

(13) Kennett et al (2009), Chelodina longicollis (Shaw 1794) - Eastern Long-Necked Turtle, Common Long-Necked Turtle, Common Snake-Necked Turtle.

(14) Australian Museum: https://australianmuseum.net.au/freshwater-crocodile

(15) Australian Museum: https://australianmuseum.net.au/water-rat

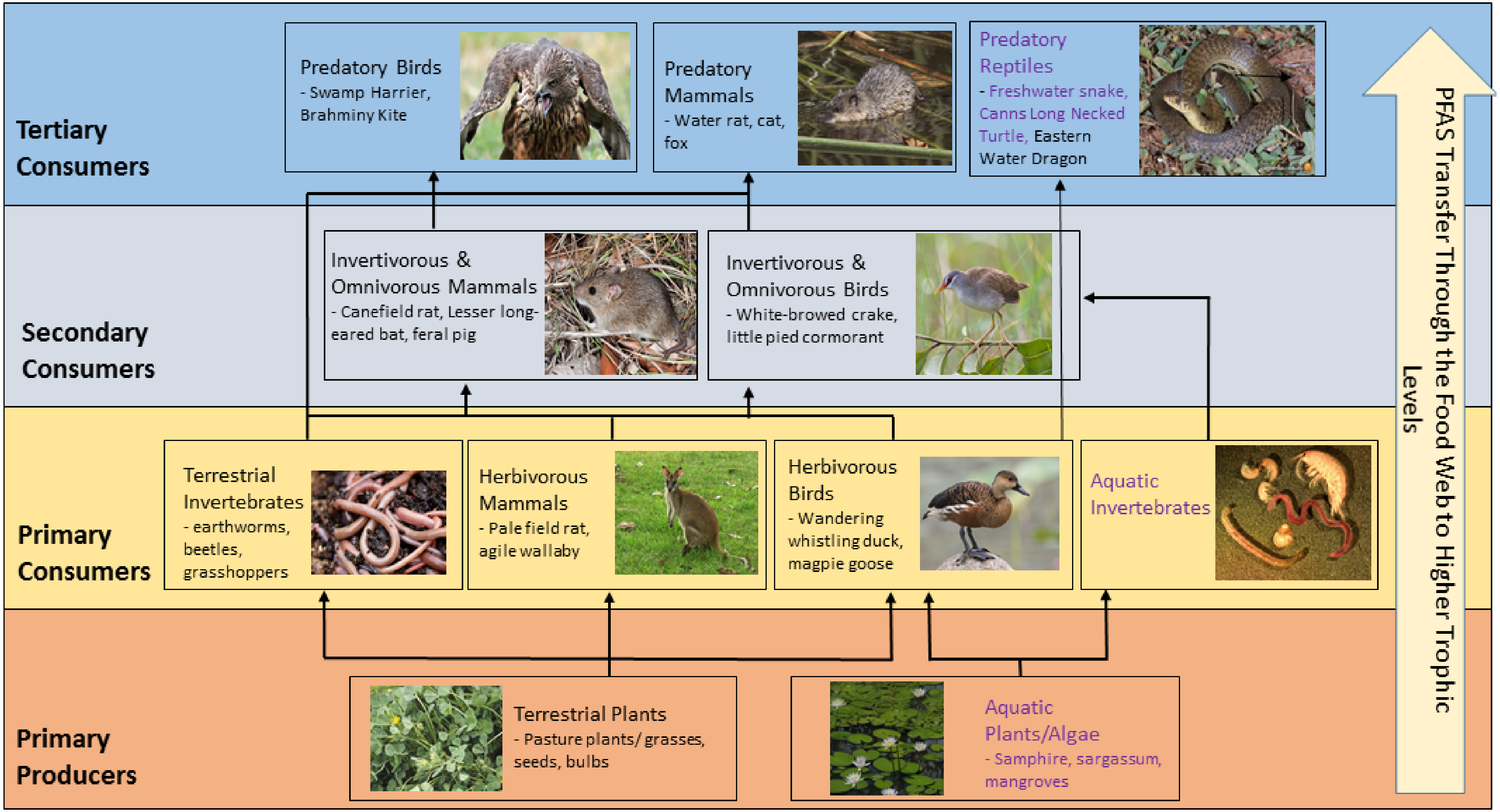
(16) Animal Diversity Web: http://animaldiversity.org/accounts/Orcaella_brevirostris/

(17) Queensland Government, Department of Environment and Heritage Protection: https://www.ehp.qld.gov.au/wildlife/animals-az/australian_snubfin_dolphin.html

7.8 FOOD WEB

Food webs have been developed for the terrestrial/semi-terrestrial and aquatic environments present within the Investigation Area. The food webs have been developed based on a combination of desktop studies and fieldworks to identify species present within the Investigation Area, as well as biota sampling for semi-terrestrial and aquatic species. This was undertaken to identify key ecological receptors in the various trophic levels (i.e. different levels within the food chain, with organisms classified on the basis of their feeding behaviour). Whilst the food webs provided below do not include all ecological receptors/species that may be present in the Investigation Area, they are considered to be indicative of what species maybe present.

A summary of the terrestrial (including semi-terrestrial) and aquatic food webs considered relevant to the Investigation Area are included as Figure 7.2 and Figure 7.3 below.



Notes:
Biota samples collected

Figure 7.2 Terrestrial and semi-terrestrial food web

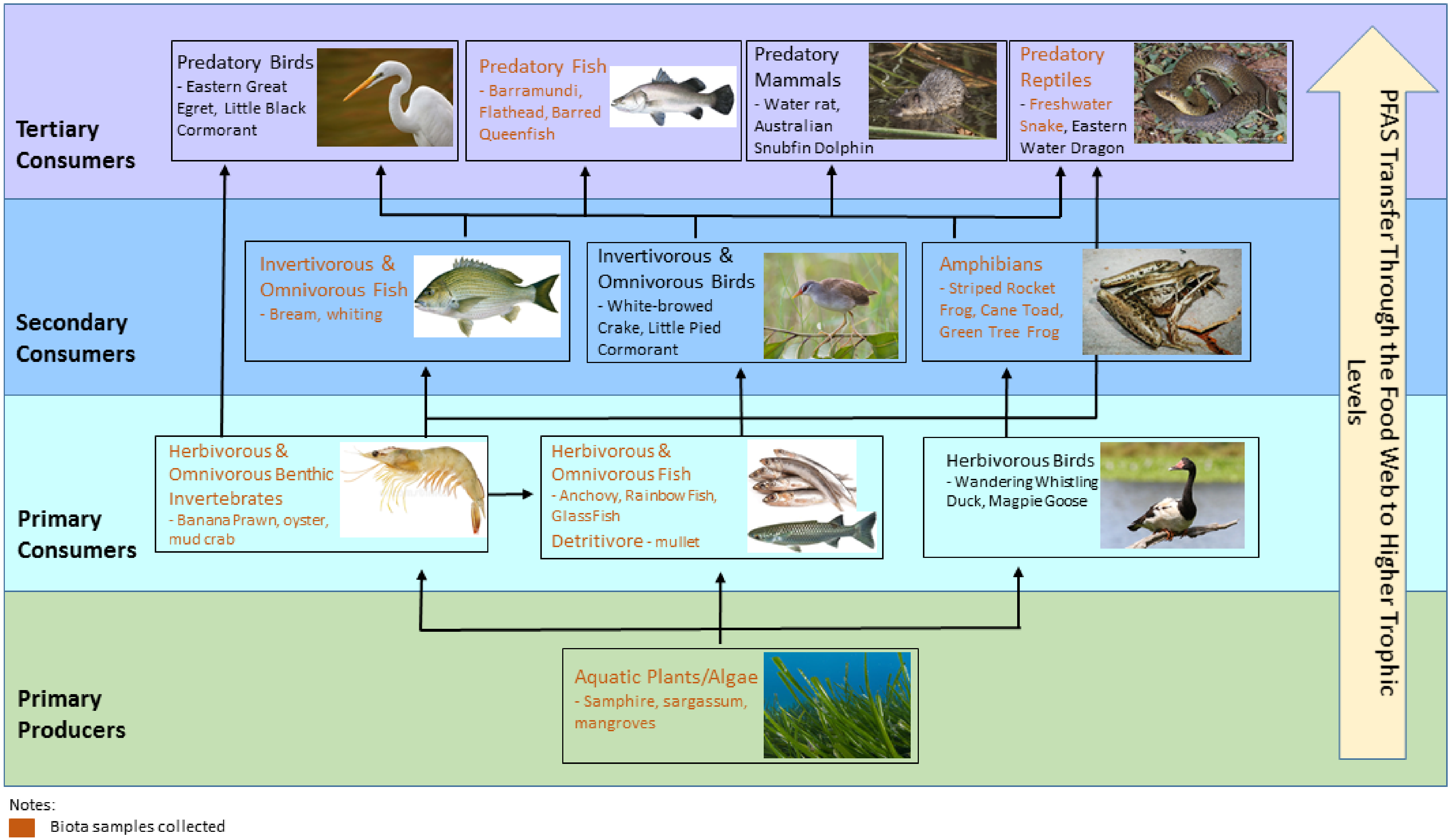


Figure 7.3 Aquatic food web (estuarine and freshwater)

8 DATA REVIEW AND SCREENING ASSESSMENT

The data obtained for soil, groundwater, surface water, sediment and biota has been reviewed to identify the characteristics and associated limitations of the data collected within each media, how data limitations are addressed, as well as a review of the quality and reliability of the data for use in the ERA. This step also reviews the data against the identified screening criteria for each media being assessed.

8.1 AVAILABLE DATA

The primary dataset used for the ERA was that obtained as part the DSI (WSP, 2018a). Additional data collected during a wet season sampling event, marine sampling event of aquatic biota; and a semi-terrestrial fauna sampling event have also been utilised in the ERA. The results were not available to be reported as part of the DSI (WSP, 2018a) but were reported in the Seasonal Monitoring Report 1 (WSP, 2018b) and a detailed review of the additional data has been completed as part of the ERA (refer Sections 8.3 and 8.4) and the relevant tabulated results are presented in Appendix B. Further details are provided below.

Data obtained for the key PFAS compounds (i.e. PFOS and PFOA) where ecological screening level criteria are available have been presented and discussed in the following sections of the ERA report.

A wet season sampling event was undertaken during March/April 2018, which included groundwater, surface water and sediment sampling. The review of available data has included both on-Base and off-Base data collected during the wet season sampling event, as well as data collected during the dry season sampling events conducted between July and August 2017.

Aquatic biota sampling and analysis was completed by ESP (2018a, 2018b, 2018c) as part of a broader assessment to evaluate both human health and ecological risks within the Investigation Area. The risk to human receptors was addressed in the HHRA completed by WSP (2018c). The available aquatic biota data (i.e. finfish, crustaceans, molluscs, and plants) for use in the ERA includes samples obtained from freshwater, estuarine and marine environments during four survey (sampling) rounds as follows:

- **Survey 1**: 12–18 July 2017
- **Survey 2**: 30 November to 03 December 2017
- **Survey 3**: 12–15 December 2017; and
- **Survey 4**: 21–26 March 2018 – marine sampling event.

Of note, the sampling strategy undertaken for fish species (where possible) included the preparation of samples for the whole fish, flesh and liver. Likewise, for crustaceans, samples were prepared for the whole, flesh and organ (where possible). In consideration of wildlife feeding habits, the data reported for whole fish and flesh samples have been utilised in calculating exposure point concentrations. This is considered reasonable as wildlife that feed on fish may either consume the whole fish and/or the flesh, but are unlikely to consume organs (i.e. the liver) in isolation, without consuming the whole fish. Hence, data for liver and/or organs has not been utilised separately for the ERA. Similarly, for crustaceans, it is considered that some wildlife species may consume them whole and others will discard the external shell and consume the flesh. Hence, data for both whole crustaceans and flesh have been utilised.

A semi-terrestrial fauna survey and biota sampling event was conducted between 22 February 2018 and 01 March 2018. The sampling event included the capture and sampling of several target amphibians and reptile species within the Town Common, Rowes Bay Wetland, Louisa Creek wetland and a comparative site along Alligator Creek. Further details regarding the assessment including the sampling methods adopted is provided in Appendix D. Data review and interpretation of the semi-terrestrial biota results has been included in this report, refer to Section 8.4.3 for further details.

As part of the data review, an assessment of the PFAS (primarily PFOS and PFOA, as well as PFHxS given it was commonly detected in most media) distribution within on and off-Base areas was undertaken. A summary of the review is provided in Appendix C.

8.2 SCREENING ASSESSMENT AND CRITERIA

Screening criteria are highly conservative and developed as a 'catch-all' and so whilst their derivation may not strongly fit the setting of each site to which they are applied, the adoption of a screening criteria is to assist in framing the assessment. A screening assessment identifies the chemicals that require further evaluation and if the identified concentrations are sufficiently elevated to require a detailed assessment of risk (i.e. exceeding screening criteria). The screening assessment for the identified soil, groundwater, sediment and surface water impacts was conducted based on the reported concentrations for each media; and the numerical criteria provided in the PFAS NEMP (January 2018).

There may appear to be an inconsistency between application of criteria on-Base as against to off-Base. This is due to active and passive controls put into effect at the Base that limit biota populations. Such controls include:

- passive – except for the western portion of the Base adjacent to The Common, surface water features within the Base are nominally dry, unless temporarily inundated because of a large rainfall event; and
- active – to limit risk to aircraft from contact with fauna, the Base and Townsville Airport put into effect actions to permanently limit access to wildlife including dispersing flocks of birds from airside areas.

Controls such as these are considered when applying screening criteria on-Base so that the ERA has greater applicability.

For aquatic biota results (including fish and crustaceans), the dataset was compared against tissue-based toxicity benchmarks as developed by Environment Canada (EC 2017). For aquatic plant biota samples, The Norwegian Pollution Control Authority (2008) 'no toxic effect concentration' to aquatic organisms has been adopted for screening purposes. For semi-terrestrial biota, the Canadian Federal Environmental Quality Guidelines (FEQG) (2017); for direct exposure to wildlife (mammalian and avian diets) were adopted for screening purposes.

The Canadian FEQG are also referenced in the PFAS NEMP (January 2018) as the terrestrial biota screening guideline values. The derivation of the Canadian FEQG assumes equilibrium partitioning between water and soil, with the target of the Canadian 95% species protection in water as the premise for calculating the solid phase criterion. The guidance also assumes at least 10 m separation between the soil source and the point of exposure in the water phase. Whilst this setting does not necessary apply to all environmental settings in Townsville, including for sediments, incongruence between guidance values and the assumptions that underpin their derivation is not sufficient to forfeit their applicability as a screening criteria in this ERA.

Further details regarding the adopted screening criteria are provided below in Sections 8.2.1 to 8.2.3.

8.2.1 TERRESTRIAL (AND SEMI-TERRESTRIAL) ENVIRONMENTS

The screening assessment for terrestrial and semi-terrestrial environments both on-Base and off-Base, has utilised available soil and sediment data collected during dry and wet season sampling events. For soil, PFAS reported in the top 2 m has been utilised, consistent with advice provided in NEPC (2013), regarding the depth relevant to terrestrial environments, this includes burrowing animals, terrestrial organisms (invertebrate sand vertebrates) and plants.

The soil criteria that are provided in the PFAS NEMP (January 2018) consider both direct exposure to flora and fauna species (i.e. earthworms and plants), as well as indirect exposure pathways which includes the potential for off-Base migration and bioaccumulation. In evaluating potential risks to ecological receptors both direct exposure pathways (which can be used to assess the potential for direct toxicity to an organism); and indirect exposure pathways need to be considered.

The criteria that are provided in the PFAS NEMP (January 2018) relate to public open space, residential and industrial/commercial land-uses (consistent with the Canadian FEQG approach). The criteria listed for 'public open space' relates to direct exposure pathways only. For residential and industrial/commercial land-uses the criteria account for the potential off-Base transport of PFAS and the bioaccumulation of PFAS within primary, secondary and tertiary consumers within the food web (EC 2017).

The relevant screening criteria adopted for on and off-Base are:

- public open space: ecological direct exposure
- residential: ecological indirect exposure; and
- industrial/commercial: ecological indirect exposure.

As indicated in the NEMP (January 2018), the residential and public open space screening criteria were derived to be protective of secondary consumers that may consume/ingest soil as part of their dietary intake or foraging habits. The industrial/commercial criteria is intended to protect against potential impacts on freshwater life, from PFOS originating in soil.

Specific guidelines for PFAS contamination in sediments are not available and so the adopted screening criteria for soil and sediment are the PFAS NEMP (January 2018) Interim soil – ecological guidelines.

Both direct and indirect exposure scenarios were applied to data collected from on-Base and off-Base as an initial screening tool.

8.2.2 AQUATIC ENVIRONMENTS AND BIOTA

WSP acknowledge that the PFAS NEMP (January 2018) advises that the 99% species level of protection be applied to moderately disturbed systems for chemicals that bioaccumulate and biomagnify in wildlife (such as PFAS). However, as discussed in the DSI (WSP, 2018a), advancement of biota sampling in the aquatic ecosystems of the Investigation Area has rendered the application of the 99% screening criteria redundant and the 95% protection level is considered adequate for the slightly to moderately disturbed ecosystems (due to the moderately disturbed ecosystems of the Town Common, Bohle River and Cleveland Bay).

Freshwater values have been adopted to evaluate all aquatic ecosystems (i.e. freshwater, estuarine and marine) including aquatic life (i.e. aquatic plants, invertebrates and fish). This criterion is relevant to evaluating potential off-Base ecological risk issues and has been adopted on-Base, to identify areas with PFAS impacts that have a potential to contribute to off-Base impacts. It is noted that aquatic biota sampling was also completed to conduct a direct evaluation of potential risks to biota.

8.2.3 TERRESTRIAL AND SEMI-TERRESTRIAL BIOTA

An assessment of PFAS in terrestrial and semi-terrestrial biota was undertaken through adoption of the screening values based on wildlife diet from the Environment and Climate Change Canada, 2017 *Draft Federal Environmental Quality Guidelines – Perfluorooctane Sulfonate (PFOS)* (EC 2017), as referenced in the PFAS NEMP (January 2018). These values are intended to protect mammalian and avian consumers of aquatic biota. The criteria represent the concentrations of PFOS in the aquatic biota food item, expressed on whole-body wet weight basis, that could be eaten by terrestrial or semi-aquatic mammalian or avian wildlife. The terrestrial biota guideline values are as follows:

- Interim – ecological direct exposure for wildlife diet:
  - Mammalian diet biota wet weight (ww) food; and
  - Avian diet biota ww food.

8.3 ON-BASE SCREENING ASSESSMENT

8.3.1 SOIL AND SEDIMENT

A review of the soil and sediment data collected within different areas across the Base (up to the post wet season sampling event to September 2018) has been undertaken to further consider potential risk issues on-Base, with a view that any identified areas (including operational areas on the Base) may potentially contribute to off-Base ecological risks. A summary of the results and comparison against adopted screening criteria is presented in Table 8.1. Comparison has been made to direct and indirect exposure scenarios. Soil sample locations are depicted on Figures 4a and 4b; and sediment sample locations are depicted on Figure 9 (shown with co-located surface water and aquatic biota sample locations), Appendix A.

Sediment data on-Base was collected from source areas and down-gradient of source areas as well as at selected up-gradient locations (i.e. drainage points coming onto Defence property). Where possible, sediment samples were collected as co-located samples with surface water samples.

Table 8.1 Review of on-Base soil and sediment concentrations

ADOPTED SCREENING CRITERIA[1,2]	PFOS	PFOA	NUMBER OF SAMPLES
INDIRECT EXPOSURE (RESIDENTIAL)	**0.01**	–	
INDIRECT EXPOSURE (INDUSTRIAL/COMMERCIAL)	0.14	–	
DIRECT EXPOSURE (PUBLIC OPEN SPACE)	1	10	
Base area and media	**Reported Concentration Range (mg/kg)**		
Fuel Farm 1 (NQ0052) and Former Fire Training Area (NQ0054)			
Soil $0 \leq 2.0$ mBGL[3]	0.004 – **73.2**	<0.0002 – 4.61	21
Sediment[4]	**0.0662**	0.0033	1
Domestic Area			
Soil $0 \leq 2.0$ mBGL[3]	<0.0002 – **0.0164**	<0.0002 – 0.0011	24
Sediment[4]	**0.0122 – 0.0358**	0.0006 – 0.0013	2
38 Squadron (SQN)			
Soil $0 \leq 2.0$ mBGL[3]	**0.0263**	0.0011	1
Sediment[4]	0.0052	<0.0002	1
Ingham Road Sports Field			
Soil $0 \leq 2.0$ mBGL[3]	<0.0002 – **0.107**	<0.0002 – 0.0008	6
Sediment[4]	<0.0002 – 0.0035	<0.0002	4
5 AVN (including Building 266, Building 295 and Building 366 & GSE Compound)			
Soil $0 \leq 2.0$ mBGL[3]	0.0082 – **0.239**	0.0006 – 0.0202	6
Sediment[4]	**0.0404 – 2.75**	0.0011 – 0.0245	6
Fire Station (NQ0055) and Former Fire Training Area (NQ0107)			
Soil $0 \leq 2.0$ mBGL[3]	0.0003 – **8.61**	<0.0002 – 0.341	17
Sediment[4]	**10.4**	0.129	1
Fuel Farm 2 (NQ0099)			
Soil $0 \leq 2.0$ mBGL[3]	0.0028 – **7.36**	0.0003 – 0.076	4
Sediment[4]	**80.2**	0.625	1
Disused Runway 13/31			
Soil $0 \leq 2.0$ mBGL[3]	0.0008 – **3.82**	<0.0002 – 0.0775	10

ADOPTED SCREENING CRITERIA(1,2)	PFOS	PFOA	NUMBER OF SAMPLES
INDIRECT EXPOSURE (RESIDENTIAL)	**0.01**	–	
INDIRECT EXPOSURE (INDUSTRIAL/COMMERCIAL)	0.14	–	
DIRECT EXPOSURE (PUBLIC OPEN SPACE)	1	10	
Base area and media	**Reported Concentration Range (mg/kg)**		
Sediment(4)	**0.818**	0.0056	1
Former Fire Training Area (NQ0106) and Ordnance Loading Aprons (OLAs) – OLA8 and OLA9			
Soil 0 ≤ 2.0 mBGL(3)	<0.0002 – **13.7**	<0.0002 – 0.392	12
Sediment(4)	**0.240 – 5.12**	0.0217 – 0.0826	3
Pad Brahman			
Soil 0 ≤ 2.0 mBGL(3)	<0.0002 – **0.0247**	<0.0002	3
Sediment(4)	**0.0234**	<0.0002	1
OLAs			
Soil 0 ≤ 2.0 mBGL(3)	0.0038 – **0.101**	<0.0002 – 0.0018	6
Sediment(4)	**0.0699** – **0.350**	0.0009 – 0.0028	2
Former Fire Training Area (NQ0105)			
Soil 0 ≤ 2.0 mBGL(3)	0.0004 – **1.31**	<0.0002 – 0.0516	11
Sediment(4)	0.0046 – **0.0987**	<0.0002 – 0.0009	10
Mount St John			
Soil 0 ≤ 2.0 mBGL(3)	<0.0002 – **0.0568**	<0.0002 – 0.0004	2
Sediment(4)	0.001 – 0.0037	<0.0002	2

(1) Ref: HEPA (January 2018) – NEMP ecological screening values.

(2) Shading indicates a concentration is above the adopted screening criteria.

(3) Includes soil data between 0 and 2.0 mBGL. Refer Table 1, Appendix B.

(4) Sediment results are presented as Table 2, Appendix B.

A review of the data indicates that PFOS concentrations within sediment and/or soil at each of the thirteen primary source areas on the Base were reported as exceeding the adopted screening criteria for indirect or direct exposure scenarios. Concentrations of PFOA within soil or sediment did not exceed adopted ecological screening criteria and was not considered to warrant further evaluation of potential ecological risks on-Base.

Reported soil concentrations in comparison to adopted screening criteria is provided as Figure 5, Appendix A.

8.3.2 GROUNDWATER AND SURFACE WATER

A review of the groundwater and surface water data collected within the various source areas across the Base (up to the post wet season sampling event to April 2018) was undertaken to further consider potential risk issues on-Base. A summary of the results and comparison against adopted screening criteria is presented in Table 8.2 below. Groundwater sample locations are shown on Figure 6a (on and off-Base) and Figure 6b (on-Base only), Appendix A.

Table 8.2 Review of on-Base groundwater and surface water data

ADOPTED SCREENING CRITERIA (µg/L)(1,2)	PFOS	PFOA	NUMBER OF SAMPLES
FRESHWATER – 95% PROTECTION LEVEL	0.13	220	
Base area and media	Reported Concentration Range (µg/L)(3)		
Former Fire Training Area (NQ0054) and Fuel Farm 1 (NQ0052)			
Groundwater	0.79 – 649	0.02 – 30.7	29
Surface water (as runoff)	48.1 – 50.6	1.78 – 4.66	2
Domestic Area and 38 Squadron			
Groundwater	<0.01 – 28.3	<0.01 – 1.2	19
Surface water	0.15 – 1.33	0.04 – 0.27	2
Ingham Road Sports Field			
Groundwater	<0.05 – 0.124	0.0056 – <0.05	8
Surface water (west of sports field)	0.0253 – 0.11	0.0027 – 0.02	2
5 Aviation (including Building 236, Building 295 and Building 366 & GSE Compound)			
Groundwater	<0.05 – 1,510	<0.05 – 61.2	24
Surface water	1.57 – 62.0	0.0652 – 4.40	10
Fire Station (NQ0055) and Former Fire Training Area (NQ0107)			
Groundwater	0.1 – 1,660	<0.05 – 86.3	29
Surface water	24.3 – 141	0.57 – 14.1	2
Fuel Farm 2 (NQ0099)			
Groundwater	2.42 – 4,080	0.05 – 394	9
Surface water	No surface water present		
Former Runway 13/31			
Groundwater	4.70 – 198	0.55 – 32.6	5
Surface water (west/south-west of runway)	2.07 – 3.07	0.17 – 0.18	2
Former Fire Training Area (NQ0106) and Ordnance Loading Aprons (OLAs)			
Groundwater	0.81 – 366	0.03 – 49.2	4
Surface water	3.77 – 4.65	0.13 – 0.19	2

ADOPTED SCREENING CRITERIA (µg/L)[1,2]	PFOS	PFOA	NUMBER OF SAMPLES
FRESHWATER – 95% PROTECTION LEVEL	**0.13**	**220**	
Base area and media	**Reported Concentration Range (µg/L)[3]**		
Pad Brahman			
Groundwater	0.01 – 33.0	<0.10 – 7.66	8
Surface water	0.0885 – 0.28	0.0062 – 0.04	2
Ordnance Loading Aprons (OLAs)			
Groundwater	<0.01 – 4.04	<0.01 – 0.21	10
Surface water	0.9 – 5.96	0.176 – 0.40	3
Former Fire Training Area (NQ0105)			
Groundwater	0.0739 – 1.06	<0.02 – 0.05	4
Surface water	0.0933 – 0.84	<0.01 – 0.030	10
Mount St John			
Groundwater	<0.01 – 0.54	<0.01 – 0.171	8
Surface water (collected from the on-Base wetland area that extends onto the Base from the Common)	0.03 – 0.166	<0.01 – 0.040	4
On-Base Wetland Area[4]			
Groundwater	<0.05 – 7.09	<0.05 – 0.58	12
Surface water	0.356 – 4.98	0.0295 – 0.142	6

(1) Ref: HEPA (January 2018) – NEMP Ecological guidance values for freshwater and marine water.

(2) Shading indicates a concentration is above the adopted screening criteria.

(3) On-Base groundwater and surface water data is presented on Tables 3 and 4, Appendix B.

(4) Groundwater samples labelled as 'W of Runway 13/31 on Table 3. Surface water samples labelled as 'The Common discharge' on Table 4, Appendix B.

With the exception of the Ingham Road sports field, groundwater and surface water collected from all on-Base source areas reported concentrations of PFOS exceeding the adopted ecological screening criteria. At Fuel Farm 2 (NQ0099), the concentration of PFOA was also reported to be above the adopted screening criteria. All remaining PFOA concentrations in groundwater collected from on-Base monitoring wells were below the adopted screening criteria. PFOA was not detected at concentrations above the adopted screening criteria within surface water on-Base. Groundwater impacts in comparison to adopted screening criteria are provided as Figures 7a, 7b and 8, Appendix A.

8.4 OFF-BASE SCREENING ASSESSMENT

The exact locations of samples collected from private water bores, a commercial property and soil samples from private residences have not been identified in this report as privacy agreements with these property owners preclude the identification of sample locations on maps.

8.4.1 SOIL AND SEDIMENT

A review of the soil and sediment data collected within different areas outside the base (up to the post wet season sampling event to September 2018) has been undertaken to further consider potential ecological risk issues off-Base. A summary of the results and comparison against adopted screening criteria is presented in Table 8.3. Where possible, sediment samples were collected as co-located samples with surface water samples. Comparison has been made to direct and indirect exposure scenarios. Off-base soil sample locations are provided on Figure 4a and sediment sample locations are depicted on Figure 9 (shown with co-located sediment, surface water and aquatic biota samples), Appendix A.

Table 8.3 Review of off-Base soil and sediment concentrations

ADOPTED SCREENING CRITERIA(1,2,6)	PFOS	PFOA	NUMBER OF SAMPLES
INDIRECT EXPOSURE (RESIDENTIAL)	**0.01**	**–**	
INDIRECT EXPOSURE (INDUSTRIAL/COMMERCIAL)	0.14	–	
DIRECT EXPOSURE (PUBLIC OPEN SPACE)	1	10	
Off-Base area and media	**Reported Concentration Range (mg/kg)**		
Bohle			
Soil 0 ≤ 2.0 mBGL(3)	<0.0002	<0.0002	3
Sediment (collected at Bohle River)	<0.0002 – 0.0031	<0.0002	10
Belgian Gardens			
Soil 0 ≤ 2.0 mBGL(3)	<0.0002	<0.0002	2
Sediment(4)	Not collected		
Cleveland Bay/Rowes Bay			
Soil 0 ≤ 2.0 mBGL(3)	<0.0002 - **0.511**	<0.0002-0.0086	13
Sediment	<0.0002 – **0.0526**	<0.0002 – 0.001	20
The Common			
Soil 0 ≤ 2.0 mBGL(3)	<0.0002	<0.0002	1
Sediment	<0.0002 – 0.0073	<0.0002 – 0.001	6
Garbutt Community			
Soil 0 ≤ 2.0 mBGL(3)	<0.0002 – **0.0116**	0.0012	17
Sediment	<0.0002 – 0.0052	<0.0002 – 0.0004	11

ADOPTED SCREENING CRITERIA[1,2,6]	PFOS	PFOA	NUMBER OF SAMPLES
INDIRECT EXPOSURE (RESIDENTIAL)	**0.01**	**–**	
INDIRECT EXPOSURE (INDUSTRIAL/COMMERCIAL)	0.14	–	
DIRECT EXPOSURE (PUBLIC OPEN SPACE)	1	10	
Off-Base area and media	**Reported Concentration Range (mg/kg)**		
Pallarenda			
Soil 0 ≤ 2.0 mBGL[3]	<0.0002 – **0.0686**	<0.0002 – 0.0034	14
Sediment[4]	Not collected		
Bushland Beach			
Soil 0 ≤ 2.0 mBGL[3]	<0.0002	<0.0002	1
SEDIMENT ONLY DATA[5]			
Commercial Property - Garbutt			
Sediment	0.0005 – **0.205**	<0.0002 – 0.0033	4
Ecological Area (located within The Town Common)			
Sediment	0.0172 – 0.096	<0.0002 – 0.0009	4
Downstream of Fuel Farm 1 (NQ0052) & Former Fire Training Area NQ0054			
Sediment	0.0009 – **0.187**	<0.0002 – 0.0008	3
Background (outside of Investigation Area)			
Sediment	<0.0002 – 0.0031	<0.0002	6

(1) Ref: HEPA (January 2018) – NEMP human health screening values for residential with garden/accessible soil.

(2) Shading indicates a concentration is above the adopted screening criteria.

(3) Includes soil data between 0 and 2.0 mBGL. Refer Table 5, Appendix B.

(4) No sediment data collected within relevant area as no surface water body/drainage channel present.

(5) Refer Table 6, Appendix B for sediment data.

(6) Refer Section 8.2 for a discussion of the limitations of the Canadian FEQG indirect exposure criteria.

A review of the off-Base soil data identified PFOS concentrations exceeding the adopted screening criteria for indirect exposure scenarios from properties in Rowes Bay/Cleveland Bay, Garbutt and Pallarenda. Concentrations of PFOA in soil off-Base did not exceed adopted ecological screening criteria. Refer to Section 11.1 for details on the direct toxicity assessment of PFAS in soil.

Sediment samples collected from Rowes Bay/Cleveland Bay (SD107, SD115, SD118, SD208, SD209), the Commercial Property in Garbutt (SD113) and downstream of Fuel Farm 1 (NQ0052) & Former Fire Training Area NQ0054 (SD119) reported concentrations of PFOS exceeding the adopted screening criteria for indirect exposure scenarios. PFOA concentrations in sediment were below the adopted ecological screening criteria at all sample locations. Figures 10a and 10b, Appendix A shows the reported sediment PFOS concentrations in comparison to adopted screening criteria.

8.4.2 GROUNDWATER AND SURFACE WATER

A review of the groundwater and surface water data collected Off-Base (up to the post wet season sampling event to October 2018) was undertaken to further consider potential ecological risk issues off-Base. A summary of the results and comparison against adopted screening criteria is presented in Table 8.4 below.

Table 8.4 Review of off-Base groundwater and surface water data

ADOPTED SCREENING CRITERIA (µg/L)[1,2]	PFOS	PFOA	NUMBER OF SAMPLES
FRESHWATER – 95% PROTECTION LEVEL	0.13	220	
Off-Base area and media	Reported Concentration Range (µg/L)[3]		
Belgian Gardens			
Groundwater	<0.01 – 0.27	<0.01 – 0.02	11
Bohle			
Groundwater	<0.0003 – 0.285	<0.01 – 0.0386	8
Surface water (collected from Bohle River)	<0.01 – 0.125	<0.05 – 0.02	10
Bushland Beach			
Groundwater	<0.05 – 0.0244	<0.0005 – <0.05	2
Cleveland Bay/Rowes Bay			
Groundwater	<0.01 – 0.22	<0.0005 – 0.02	13
Surface water	<0.05 – 11.7	<0.01 – 1.18	20
Garbutt Community			
Groundwater	<0.0003 – 9.89	<0.0005 – 0.37	39
Surface water	<0.0003 – 0.14	<0.01 – 0.04	11
Mount St John			
Groundwater	<0.0003 – 0.0007	<0.05 – 0.0005	4
Pallarenda			
Groundwater	<0.05 – 0.05	<0.0005 – <0.05	6
Rowes Bay Landfill			
Groundwater	<0.01 – 0.12	<0.01 – 0.0021	9
The Common[4]			
Groundwater	<0.01 – 0.06	<0.0005 – 0.08	16
Surface Water	<0.1 – 3.45	<0.05 – 0.23	10

ADOPTED SCREENING CRITERIA (µg/L)[1,2]	**PFOS**	**PFOA**	**NUMBER OF SAMPLES**
FRESHWATER – 95% PROTECTION LEVEL	**0.13**	**220**	
Off-Base area and media	**Reported Concentration Range (µg/L)[3]**		
Commercial Property – Garbutt			
Groundwater	<0.01 – 6.13	<0.01 – 0.39	32
Surface Water	<0.01 – 18.4	0.05 – 2.68	6
Private extraction bores (suburbs of Pallarenda, Rowes Bay, Belgian Gardens, West End and Garbutt)			
Groundwater	<0.0003 – 0.556	<0.0005 – 0.0895	55
Background (outside Investigation Area)			
Surface Water	<0.0003 – 0.0053	<0.0005 – 0.0009	6

(1) Ref: HEPA (January 2018) – NEMP Ecological-based guidance values for freshwater and marine water.

(2) Shading indicates a concentration is above the adopted screening criteria.

(3) Off-Base groundwater and surface water results are presented on Tables 7 and 8, Appendix B.

(4) Includes groundwater water and surface water samples labelled as 'Ecological Area and Town Common'. Refer to Tables 7 and 8, Appendix B.

A review of the off-Base groundwater data indicated the following:

— Concentrations of PFOS in groundwater exceeded the adopted freshwater screening criteria in samples collected from Belgian Gardens, Bohle, Cleveland Bay/Rowes Bay, Garbutt Community, the Commercial Property located in Garbutt and private extraction bores.

— The highest concentrations of PFOS in groundwater, 6.13 µg/L (MW457) and 6.64 µg/L (MW223), were collected from the Commercial Property located in Garbutt and the Garbutt Community respectively. MW223 is located adjacent the eastern Base boundary and as reported in the DSI (WSP, 2018a), PFAS impacts are considered representative of on-Base impact rather than an off-Base source. This impact is considered to have resulted from groundwater transport (off-Base), from the former Fire Training Area NQ0054 and Fuel Farm 1 (NQ0052).

— The concentration of PFOA in groundwater was below the adopted ecological screening criteria at all sample locations.

A review of the off-Base surface water data indicated the following:

— Concentrations of PFOS in surface water exceeded the adopted freshwater screening criteria in samples collected from Cleveland Bay/Rowes Bay, Garbutt Community, The Common, the Commercial Property in Garbutt and the Ecological Area (within The Common).

— The highest concentrations of PFOS, 11.7 µg/L (SW106) and 18.4 µg/L (SW117), were collected from the Ecological Area and the Commercial Property in Garbutt respectively. SW106 was collected from the tributary that drains the eastern section of former fire training ground NQ0105.

— The concentration of PFOA in surface water was below the adopted ecological screening criteria at all sample locations.

Reported groundwater concentrations in comparison to adopted screening criteria are provided as Figures 7a, 7b and 8, Appendix A. Reported surface water concentrations in comparison to adopted screening criteria are provided as Figures 11a and 11b, Appendix A.

8.4.3 TERRESTRIAL AND SEMI-TERRESTRIAL BIOTA

A review of the semi-terrestrial biota data collected off-Base in February/March 2018 was undertaken to further consider potential risk issues to ecological receptors. A summary of the results and comparison against adopted screening criteria is presented in Table 8.5.

Table 8.5 Review of on-Base and off-Base terrestrial and semi-terrestrial biota data

ADOPTED SCREENING CRITERIA (µg/kg) (1,2)	PFOS	PFOA	NUMBER OF SAMPLES
MAMMALIAN WILDLIFE DIET	*4.6*	NA(4)	
AVIAN WILDLIFE DIET	8.2	NA(4)	
SAMPLE LOCATION	REPORTED CONCENTRATION RANGE (µg/kg WET WEIGHT)(3)		
Rowes Bay – Estuarine and Marine			
Cane Toad	*8 – 643*	<1	6
Canns Longnecked Turtle	*<1 – 699*	<1	6
Freshwater Snake	191 – *954*	<1	6
Green Tree Frog	*7 – 190*	<1 – 1	6
Striped Rocket Frog	25 – *128*	<1	6
Town Common – Estuarine			
Cane Toad	*17 – 346*	<1	6
Canns Longnecked Turtle	*79 – 2,537*	<1	6
Freshwater Snake	*1,275 – 14,915*	<1 – 1	6
Green Tree Frog	*4 – 75*	<1	5
Striped Rocket Frog	*2 – 409*	<1	6
Louisa Creek – Estuarine and Freshwater			
Cane Toad	*9 – 58*	<1	6
Canns Longnecked Turtle	*78 – 117*	<1	2
Freshwater Snake	*645*	<1	1
Green Tree Frog	None collected at this location		
Striped Rocket Frog	*22*	<1	2
Alligator Creek – Estuarine and Freshwater (off-Base Comparative Site):			
Cane Toad	*<1 – 12*	<1	6
Canns Longnecked Turtle	None collected at this location		
Freshwater Snake	<1	<1	4
Green Tree Frog	<1 – 1	<1	4
Striped Rocket Frog	None collected at this location		

(1) Ref: HEPA (2018). NEMP Terrestrial biota guideline values.

(2) Shading indicates a concentration is above the adopted screening criteria

(3) Semi-terrestrial biota results are presented on Table 9, Appendix B.

(4) NA – criteria not available for PFOA.

A review of the terrestrial and semi-terrestrial biota data indicated the following:

- Concentrations of PFOS within biota samples from Rowes Bay, Town Common and Louisa Creek reported concentrations exceeding adopted ecological screening criteria for each species, with the exception of the green tree frog which was not collected at Louisa Creek.
- While no screening criteria are available for PFOA, concentrations were generally below the detection limit except for three samples with concentrations reported at 1 µg/kg. The samples were collected from Rowes Bay (2x green tree frogs) and the Town Common (1x freshwater snake).
- One cane toad sample collected from the comparative site along Alligator Creek, reported a concentration of 12 µg/kg, exceeding the adopted screening criteria. Remaining biota samples from the comparative site were below the screening criteria.

Semi-terrestrial sampling locations are provided as part of the semi-terrestrial biota sampling report (WSP 2018d), presented in this report as Appendix D.

8.4.4 AQUATIC BIOTA

A review of the aquatic biota data collected off-Base (across four survey (sampling) rounds between July 2017 and March 2018) was undertaken to further consider potential risk issues off-Base. A summary of the results and comparison against adopted screening criteria is presented in Table 8.6. Aquatic biota sampling locations are shown on Figure 9, Appendix A.

Table 8.6 Review of off-Base aquatic biota data

ADOPTED SCREENING CRITERIA	PFOS	PFOA	NUMBER OF SAMPLES
MAMMALIAN WILDLIFE DIET(1)	*4.6*	**NA**	
AVIAN WILDLIFE DIET(1)	8.2	**NA**	
SAMPLE LOCATION	**REPORTED CONCENTRATION RANGE (µg/kg WET WEIGHT)(2,3)**		
Bohle River (Estuarine):			
Finfish(4) (Whole)	*7 – 152*	<1 – 1	11
Finfish (Flesh)	*<1 – 9*	<1	21
Crustaceans (Whole)	*59*	<1	1
Crustaceans (Flesh)	<1 – 4	<1	17
Molluscs (Oyster)	<1	<1	2
Plant (samphire)	<1	<1	1
Bohle River (Freshwater):			
Finfish(4) (Whole)	*14-17*	<1	2 (composite samples)
Finfish (Flesh)	No fish flesh or crustaceans sampled due to lack of success in capturing species within the freshwater waterway		
Crustaceans (Whole)			
Crustaceans (Flesh)			
Molluscs (Oyster)	No oyster samples caught at this location		
Plant (samphire, mangrove, seagrass)	No plant samples collected at this location		

ADOPTED SCREENING CRITERIA	PFOS	PFOA	NUMBER OF SAMPLES
MAMMALIAN WILDLIFE DIET[1]	*4.6*	NA	
AVIAN WILDLIFE DIET[1]	8.2	NA	
SAMPLE LOCATION	REPORTED CONCENTRATION RANGE (µg/kg WET WEIGHT)[2,3]		
Bohle River (Marine)			
Finfish (Whole)	No whole fish samples caught at this location		
Finfish (Flesh)[4]	<1 – 2	<1	42
Crustaceans (Whole)	No whole samples caught at this location		
Crustaceans (Flesh)	*<1 – 6*	<1	4
Molluscs (Oyster)	No oysters caught at this location		
Plant (samphire, mangrove, seagrass)	No plant samples collected at this location		
Mundy Creek (Estuarine – drains from the Base into Rowes Bay):			
Finfish[5] (Whole)	*5 – 38*	<1	8
Finfish (Flesh)	1	<1	1
Crustaceans (Whole)	*36*	<1	1
Crustaceans (Flesh)	<1 – 1	<1	2
Molluscs (Oyster)	No oysters caught at this location		
Plant (samphire includes samples collected from Mundy Creek and Mundy Creek Wetland)	<1	<1	2
Rowes Bay (Estuarine):			
Finfish (Whole)	No whole samples caught at this location		
Finfish[6] (Flesh)	<1 – 1	<1	3
Crustaceans (Whole)	No whole samples caught at this location		
Crustaceans (Flesh)	<1	<1	1
Molluscs (Oyster)	No oysters caught at this location		
Plant (mangrove)	<1	<1	8
Rowes Bay (Marine):			
Finfish (Whole)	No whole samples caught at this location		
Finfish (Flesh)[6]	<1	<1	30
Crustaceans (Whole)	No whole samples caught at this location		
Crustaceans (Flesh)	<1 – 4	<1	4
Molluscs (Oyster)	No oysters collected at this location		
Plant (sargassum)	<1	<1	3

ADOPTED SCREENING CRITERIA	PFOS	PFOA	NUMBER OF SAMPLES
MAMMALIAN WILDLIFE DIET(1)	*4.6*	NA	
AVIAN WILDLIFE DIET(1)	8.2	NA	
SAMPLE LOCATION	REPORTED CONCENTRATION RANGE (µg/kg WET WEIGHT)(2,3)		
Three Mile Creek (Estuarine – drains from the Base into Rowes Bay):			
Finfish(7) (Whole)	*2 – 19*	<1	5
Finfish (Flesh)	No flesh samples analysed at this location		
Crustaceans (Whole)	No whole samples analysed at this location		
Crustaceans (Flesh)	<1	<1	3
Molluscs (Oyster)	No oysters caught at this location		
Plant (samphire)	<1	<1	1
Town Common (Estuarine):			
Finfish(8) (Whole)	*12 – 267*	<1	15
Finfish (Flesh)	*<1 – 59*	<1	19
Crustaceans (Whole)	*50*	<1	1
Crustaceans (Flesh)	*<1 – 54*	<1 – 1	24
Molluscs (Oyster)	No oysters caught at this location		
Plant (mangrove, samphire)	0.5	<1	9
Alligator Creek (Comparative Site – Estuarine and Freshwater):			
Finfish (Whole)	<1	<1	2
Finfish(9) (Flesh)	<1	<1	11
Crustaceans (Whole)	<1	<1	1
Crustaceans (Flesh)	<1	<1	11
Molluscs (Oyster)	No oysters caught at this location		
Plant	No plant samples collected at this location		

ADOPTED SCREENING CRITERIA	PFOS	PFOA	NUMBER OF SAMPLES
MAMMALIAN WILDLIFE DIET[1]	*4.6*	NA	
AVIAN WILDLIFE DIET[1]	8.2	NA	
SAMPLE LOCATION	REPORTED CONCENTRATION RANGE (µg/kg WET WEIGHT)[2,3]		
Althaus Creek (Comparative Site – Estuarine):			
Finfish[10] (Whole)	<1	<1	9
Finfish (Flesh)	*<1 – 6*	<1	35
Crustaceans (Whole)	No whole samples analysed at this location		
Crustacean (Flesh)	<1	<1 – 2	14
Molluscs (Oyster)	<1	<1	2
Plant (samphire)	<1	<1	1
Gordon Creek (Comparative Site Estuarine – referred to as Stuart Creek in the DSI report (WSP 2018a)):			
Finfish[11] (Whole)	<1 – 2	<1	9
Finfish (Flesh)	<1	<1	2
Crustaceans (Whole)	2	<1	1
Crustacean (Flesh)	<1	<1	3
Molluscs (Oyster)	<1	<1	1
Plant (samphire)	<1	<1	1
Sandfly Creek (Comparative Site Estuarine):			
Finfish) (Whole)	1	<1	1
Finfish[12] (Flesh)	<1	<1	15
Crustaceans (Whole)	No whole samples analysed at this location		
Crustacean (Flesh)	<1	<1	6
Molluscs (Oyster)	No oysters caught at this location		
Plant (mangrove)	<1	<1	10

ADOPTED SCREENING CRITERIA	PFOS	PFOA	NUMBER OF SAMPLES
MAMMALIAN WILDLIFE DIET(1)	*4.6*	NA	
AVIAN WILDLIFE DIET(1)	8.2	NA	
SAMPLE LOCATION	REPORTED CONCENTRATION RANGE (µg/kg WET WEIGHT)(2,3)		
Magnetic Island (Comparative Site Marine):			
Finfish (Whole)	No whole samples analysed at this location		
Finfish(13) (Flesh)	<1	<1	14
Crustaceans (Whole)	No whole samples analysed at this location		
Crustacean (Flesh)	No flesh samples analysed at this location		
Molluscs (Oyster)	No oysters caught at this location		
Plant (sargassum, seagrass)	<1	<1	8

(1) Ref: HEPA (2018). NEMP Terrestrial biota guideline values.

(2) Shading indicates a concentration is above the adopted screening criteria.

(3) Aquatic biota data (as reported by ESP) is presented on Table 10, Appendix B.

(4) Finfish species at Bohle River: freshwater Glassfish, Rainbow fish, Mullet, Bream, Sliver biddy, Silver Javelin, Gizzard shad, Ponyfish, Mangrove Jack, Flathead, Grunter, Catfish, Pikey Bream, Yellowfin Bream, Northern Sand flathead, Barramundi, Barred queenfish, Diamond scale mullet.

(5) Finfish species at Mundy Creek: Mullet, Glassfish, Silver javelin, Silver biddy and Ponyfish.

(6) Finfish species at Rowes Bay: Mullet, Cod, Mangrove Jack, Golden snapper, Spanish mackerel, Spotted scat and Barred javelin, Barred queenfish, Northern sand flathead, Blue Threadfin salmon, Blue catfish, Barred queenfish, Golden Trevally, Sea mullet and Diamond scale mullet.

(7) Finfish species at Three Mile Creek: Ponyfish, Mullet, Silver javelin, Silver biddy and Glassfish.

(8) Finfish species at Town Common: Mullet, Silver javelin, Ponyfish, Bream, Whiting, Mullet, Gizzard shad, Silver biddy, Queenfish, Anchovy, Cod, Grunter and Glassfish.

(9) Finfish species at Alligator Creek: Rainbow fish, Freshwater glassfish, Grunter, Queenfish, Bream and Mullet.

(10) Finfish species at Althaus Creek: Mullet, Moses perch, Bream, Silver javelin, Gizzard shad, Ponyfish and Southern Herring.

(11) Finfish species at Gordon Creek: Gizzard Shad, Silver biddy, Glassfish, Ponyfish, Silver javelin, Moses perch and mullet.

(12) Finfish species at Sandfly Creek: Mullet, Bream, Mangrove jack, grunter, Whiting, Threadfin salmon, Queenfish and Anchovy.

(13) Finfish species at Magnetic island: Garfish, Sea mullet, Diamond scale mullet, Whiting, Saddletail snapper and Crimson snapper.

A review of the aquatic biota data indicated the following:

— The concentration of PFOS in finfish c from the Bohle River (estuarine) exceeded both the mammalian and avian consumers of aquatic biota criteria. The concentrations of PFOS in crustaceans only exceeded the mammalian wildlife diet criteria.

— The concentrations of PFOS in finfish from the Bohle River (freshwater) exceeded both the mammalian and avian consumers of aquatic biota criteria.

— The concentrations of PFOS in finfish and/or crustacean samples collected from Mundy Creek (estuarine), Three Mile Creek (estuarine) and the Town Common (estuarine) exceeded the adopted wildlife diet guideline values for mammalian and/or avian consumers of aquatic biota. The maximum concentration of 267 µg/kg was from a detritivore sample collected in the Town Common. Whole fish samples collected from Three Mile Creek also exceeded the adopted wildlife diet guideline values.

- The concentration of PFOS in finfish from the comparative location Althaus Creek exceeded the adopted wildlife diet guideline value for mammalian. The maximum concentration reported was 6 µg/kg.
- Limited mollusc samples were able to be collected (i.e. two from Bohle River and three from comparative locations Gordon Creek and Althaus Creek). However, PFOS and PFOA concentrations were below the laboratory limit of reporting (LOR).
- PFOA was only detected within one finfish sample (silver biddy) collected from the Bohle River (estuarine) at the limit of reporting (i.e. 1 µg/kg).
- Of the plant samples collected (samphire and sargassum), one sample of samphire from the Town Common reported a detectable concentration of PFOS (0.5 µg/kg), while all remaining samples were less than the LOR. This result was for the PFOS (linear) isomer. The total PFOS result (which includes both the linear and branched isomers of PFOS) for this sample was reported as <1 (i.e. <LOR).

8.5 DATA QUALITY

Some data quality issues were identified as part of the DSI (WSP, 2018a), notably the soil results for some PFAS compounds varied between the primary (ALS) and secondary (Eurofins) laboratories. Results reported by the secondary laboratory in some instances were higher than the primary laboratory result. It is expected that both sample heterogeneity and differences in analytical procedures are both contributing to the variation observed in the results. This is not considered to make a material difference to the dataset adopted for the ERA. The purpose of the secondary laboratory sample is to provide a check on the primary laboratory result and reproducibility of the data.

Irrespective of the primary or secondary laboratory result, a 95% upper confidence limit (UCL) was calculated for each media being assessed and was utilised in the ERA to represent the concentration that an ecological receptor may be exposed to. Hence, this is considered to provide a conservative estimate and representation of PFAS concentrations in soil, as well as the other media being assessed as part of the ERA.

8.6 DATA GAPS AND LIMITATIONS

The DSI (WSP, 2018a) collected samples of soil, groundwater, surface water, sediment and locally sourced wild foods including finfish, crustaceans, molluscs and one type of edible aquatic plant (samphire). Other aquatic plant data was also collected for seagrass, mangroves and sargassum (a macro-algae), all of which are examples of primary producers.

Terrestrial biota data (flora or fauna) including the foliage and/or fruit from terrestrial plants were not sampled as part of the DSI (WSP, 2018a). However, data obtained for several aquatic plant species (i.e. mangroves, samphire, seagrass and sargassum) has been substituted (where appropriate) to evaluate potential PFAS exposures and uptake by plants; and species whose dietary intake comprises plants/foliage. Given the semi-terrestrial and aquatic habitat interactions identified within the Investigation Area (refer to the food webs presented in Section 7.8), this approach is considered reasonable in the absence of site-specific terrestrial biota data. Identified data gaps and limitations are presented below in in Table 8.7.

Terrestrial invertebrates were not sampled as part of the DSI. As a substitute for the ERA, reported terrestrial invertebrate data (earthworms) from AECOM (2016) has been utilised to evaluate this exposure pathway for relevant species.

8.7 ADEQUACY OF DATA

Based on a review of the datasets including soil, groundwater, surface water, sediment, aquatic and semi-terrestrial biota, collectively the data is considered adequate to provide an initial characterisation of potential ecological risks, within the Investigation Area. Whilst, limitations and data gaps have been identified above and as per Table 8.7 below, efforts to address them adequately have been undertaken as part of this iteration of the ERA.

Table 8.7 Summary of data gaps and limitations

DATA GAP/LIMITATION	POTENTIAL IMPACT ON THE ERA	HOW ADDRESSED IN THE ERA
General		
Some aquatic and semi-terrestrial biota types (i.e. various fish, reptile and amphibian species) comprised less than 10 samples for individual biota sampling areas (i.e. three Mile Creek, Mundy Creek, Rowes Bay etc.), which is considered to be less than the desired sample size (n) for statistical analysis.	Limited sample sizes for biota species may contribute to an increased margin of error, resulting in over or under-estimation of potential risks to ecological receptors.	The data utilised for aquatic and semi-terrestrial biota types (i.e. finfish, crustaceans, amphibians and reptiles) at the sampled locations has incorporated all finfish, crustacean, and amphibian data for each species collectively. No further separation of the data into specific finfish species (i.e. mullet or bream), crustacean or amphibians has been undertaken at this stage. However, the calculation and adoption of 95% UCL concentrations for each biota type is conservative for the evaluation of direct toxicity as well as quantitative food web modelling. Where, a 95% UCL concentration was not appropriate to adopt, both the maximum and/or average concentrations were considered. The statistical analysis conducted for the biota datasets (aquatic and semi-terrestrial) are presented in Appendix F. NB: Two exposure point concentrations have been calculated for reptiles. One that is inclusive of all reptile data (i.e. freshwater snake and Canns Longnecked turtle); and an exposure point concentration that excludes freshwater snakes, to evaluate potential dietary exposure to this species (i.e. a freshwater snake eats other reptiles but not its own species).
No seasonal biota (aquatic or semi-terrestrial) sampling completed to evaluate the seasonal variability of PFAS concentrations	An absence of biota data under variable climatic conditions means there is no potential to understand how concentrations may vary in biota due to seasonal changes.	It has been assumed that the biota data obtained is representative of PFAS concentrations present within biota at the time of sampling and irrespective of seasonal variations (and how this may alter the concentrations observed) provides an indication of potential exposure to identified receptors.

DATA GAP/LIMITATION	POTENTIAL IMPACT ON THE ERA	HOW ADDRESSED IN THE ERA
Aquatic		
Limited availability of easily accessible freshwater habitats during biota sampling events.	The outcomes of the ERA are not considered to be impacted by the limited available data for freshwater habitats.	The current aquatic biota sampling results from the estuarine environments and where sampled freshwater environments have been utilised to estimate exposures as part of the ERA. The requirement to conduct additional sampling within freshwater environments may be further investigated as part of the iterative process for conducting the ERA and as part of Defence's response management actions on the Base.
Terrestrial and semi-terrestrial		
No site-specific terrestrial plant data collected	This is considered a data gap for species that feed on terrestrial plants as part of their dietary composition, which could result in underestimating exposure risks.	Adoption of the AECOM (2016) terrestrial plant data. In the absence of site-specific data, and given that this data was based on direct measurements of biota, this is considered a reasonable approach to address this data gap.
No site-specific terrestrial invertebrate data	This is considered a data gap for species that feed on terrestrial invertebrates as part of their dietary composition, which could result in underestimating exposure risks.	Adoption of AECOM (2016) terrestrial invertebrate data collected for earthworms. In the absence of site-specific data, and given that this data was based on direct measurements of biota, this is considered a reasonable approach to address this data gap.
No samples have been collected from higher order species (i.e. predatory birds, mammals).	In the absence of having site-specific data, the ERA has relied upon theoretical modelling and available published data to evaluate potential risks to high order species. This is likely to introduce a level of uncertainty into the estimation of potential risks and may over or underestimate actual exposures.	The sampling of some semi-terrestrial fauna species including higher order species (i.e. reptiles) was undertaken during the semi-terrestrial fauna assessment. This dataset (whilst small) is considered to provide an indication of biomagnification that may be occurring within the higher trophic levels of the semi-terrestrial food web.
There are significant limitations with the collection of bird samples and bird eggs. The collection of adequate samples to observe meaningful results was not possible or approved as part of the semi-terrestrial biota sampling program.	To assess bird exposures (including bird eggs and consumption of bird eggs by predatory birds, reptiles or mammals), the ERA has relied upon theoretical modelling and available published data as a substitute for site-specific data. This approach may over or underestimate actual exposure risks.	In the absence of site-specific data, theoretical modelling and available published data regarding exposure point concentrations has been adopted, to evaluate potential risks to these receptors. An evaluation of the adopted exposure point concentrations (and inherent limitations and assumptions) has been completed as part of the uncertainty analysis.

9 EXPOSURE ASSESSMENT

To calculate exposures to the selected receptors, an exposure assessment has been undertaken which identifies the exposure pathways to be evaluated, and the exposure point concentrations and exposure factors to be used. As wet and dry season data has been collected, a statistical analysis has been performed separately for dry and wet season results, as well as a combination of dry and wet season data to inform the decision factors for selecting a representative exposure point concentration for each media. Further details are provided in Section 9.3.

9.1 EXPOSURE PATHWAYS

For a receptor to be exposed to a chemical at a site, a complete exposure pathway must exist. An exposure pathway describes the path a chemical takes from the source to the exposed receptors and generally includes the following elements (US EPA 1989):

- a source and mechanism of chemical release
- a retention or transport medium (or media where chemicals are transferred between media)
- a point of potential contact with the contaminated medium (it should be noted that a contaminated medium is considered to be the one in which chemicals of potential concern are reported above adopted relevant screening criteria); and
- an exposure route (i.e. ingestion of plants, soil, biota) at the point of exposure.

If all elements are present in a system, the source-pathway-receptor linkage is considered complete and a receptor is potentially at risk. If one of the components is absent, then the source-pathway-receptor linkage is broken. Hence, no risk is considered to be present.

9.1.1 INCOMPLETE EXPOSURE PATHWAYS

Based on a review of available data for the site, the following exposure pathways provided below are considered incomplete (i.e. source-pathway-receptor linkage is absent):

- Dermal uptake of PFAS from environmental media. Dermal uptake is a minor pathway for PFAS exposure based on our current understanding of the compounds' ability to cross into and through dermal membranes.
- Direct contact with groundwater within the Investigation Area has not been considered for the ERA as direct sampling of surface water has been undertaken in the various surface water bodies which are connected to the site. It is understood there is potential for groundwater seeps to occur in areas within the Investigation Area (i.e. lower reaches of Mundy Creek). However, this is likely to occur following heavy rain events. A direct assessment of the potential toxicity associated with the consumption/ingestion of surface water PFAS impacts is considered to be a more appropriate approach, as the potential exposure to groundwater is likely to be intermittent.

Of note, the ingestion of PFAS in groundwater was not evaluated as a separate exposure scenario. It has been assumed that surface water samples including samples collected in areas where groundwater is known to discharge to surface waters will provide a better representation of potential exposures as a result of water ingestion.

9.1.2 COMPLETE EXPOSURE PATHWAYS

Based on a review of available data for the site, the following exposure pathways provided below are considered complete (i.e. source-pathway-receptor linkage is complete):

TERRESTRIAL AND SEMI-TERRESTRIAL ORGANISMS:

- Incidental ingestion of PFAS adhered to soil and sediment (i.e. animals – invertebrates and vertebrates).
- Uptake and bioaccumulation of PFAS from soil moisture (i.e. plants).
- Ingestion of dissolved PFAS in water sources (i.e. animals drinking from and/or inhabiting water sources).
- Ingestion of PFAS that has bioaccumulated in food sources (i.e. animals – invertebrates and vertebrates).

Of note, the uptake and bioaccumulation of PFAS from the environment into plants on-Base was assessed based on a comparison to soil data only and was inferred to be complete. Off-Base impacts have been assessed via direct measurement of PFAS in plant samples (samphire, mangrove, seagrass) and observed to be below the limit of reporting (indicating an incomplete exposure pathway). Therefore, this exposure pathway wasn't included in food web modelling.

AQUATIC ORGANISMS (ESTUARINE AND FRESHWATER):

- Incidental ingestion of PFAS adhered to sediment (i.e. animals – invertebrates and vertebrates).
- Uptake and bioaccumulation of PFAS from sediment pore water and/or surface water (all aquatic organisms).
- Ingestion of PFAS that has bioaccumulated in food sources (i.e. animals – invertebrate sand vertebrates).

The uptake and bioaccumulation of PFAS into aquatic plants and algae has been assessed via direct measurement of PFAS in plant samples. Theoretical modelling of bioaccumulation into aquatic plants was not considered appropriate given the significant variability in potential exposure concentrations in surface water.

Only ecological exposure pathways that are considered complete have been taken forward in food web modelling for the selected receptors. The exposure pathways are based on the dietary and behavioural patterns of the identified receptors. Ecological exposure pathways that have been included as part of food web modelling are summarised in Table 9.1.

Table 9.1 Ecological exposure pathways – terrestrial/semi-terrestrial and aquatic food webs

RECEPTOR (COMMON NAME)	EXPOSURE PATHWAYS FOR PFAS			
	Ingestion (diet)	Ingestion (Water)	Incidental Ingestion (Soil/Sediment)	Rationale
TERRESTRIAL / SEMI-TERRESTRIAL				
Herbivorous Mammals				
Pale Field Rat	✓	✓	✓	Some incidental ingestion of soil is assumed during grazing.
Agile Wallaby	✓	✓	✓	
Invertivorous and omnivorous mammals				
Canefield Rat	✓	✓	✓	Assumed to incidentally ingest soil during consumption of soil dwelling invertebrates and fungi.
Lesser Long-Eared Bat	✓	✓	✓	
Herbivorous Birds				
Wandering Whistling-Duck	✓	✓	✓	Some incidental ingestion of soil/sediment is assumed during foraging.
Magpie Goose	✓	✓	✓	
Invertivorous and omnivorous birds				
White-browed Crake	✓	✓	✓	Some incidental ingestion of soil/sediment is assumed for all these species due to their feeding habits. The White-browed Crake and Little Pied Cormorant have been used to assess exposure via both terrestrial and aquatic (freshwater) pathways.
Little Pied Cormorant	✓	✓	✓	
Pacific Black Duck	✓	✓	✓	
Predatory Mammals				
Water Rat	✓	✓	✓	Some incidental ingestion of soil/sediment is assumed during foraging and feeding.

RECEPTOR (COMMON NAME)	EXPOSURE PATHWAYS FOR PFAS			
	Ingestion (diet)	Ingestion (Water)	Incidental Ingestion (Soil/Sediment)	Rationale
Predatory Reptiles				
Eastern Water Dragon	✓	✓	✓	Assumed to incidentally ingest soil/sediment during foraging and feeding.
Freshwater Snake	✓	✓	×	Diet mainly comprises amphibians and ingestion of soil/sediment has assumed to be negligible.
Canns Longnecked Turtle	✓	✓	×	Diet predominantly comprises invertebrates, fish and amphibians. Ingestion of soil/sediment is assumed to be negligible.
Australian Freshwater Crocodile	✓	✓	×	Diet predominantly comprises invertebrates, fish and some small animals. Ingestion of soil/sediment is assumed to be negligible.
Predatory Birds				
Swamp Harrier	✓	×[1,2]	×	Diets are predominantly fish, invertebrates, reptiles, amphibians, other birds and mammals, and ingestion of soil and water is assumed to be negligible.
Brahminy Kite	✓	×[1,3]	×	
Black Kite	✓	×[1,3]	×	
AQUATIC (ESTUARINE & FRESHWATER)				
Herbivorous Mammals				
Dugong	✓	✓	×	Diet comprises entirely of seagrass with some macro-invertebrates. For the purposes of the ERA, it was assumed the whole diet is sourced from seagrass beds.

RECEPTOR (COMMON NAME)	EXPOSURE PATHWAYS FOR PFAS			
	Ingestion (diet)	Ingestion (Water)	Incidental Ingestion (Soil/Sediment)	Rationale
Invertivorous/Omnivorous Aquatic Birds				
White-browed Crake	✓	✓	✓	As per the terrestrial food web above.
Little Pied Cormorant	✓	✓	✓	
Predatory Birds				
Eastern Great Egret	✓	✓	×	These species feed mainly on fish and ingestion of soil/sediment is assumed to be negligible.
Little Black Cormorant	✓	✓	×	
Predatory Reptiles				
Freshwater Snake	✓	✓	×	Diet mainly comprises amphibians and ingestion of soil/sediment has assumed to be negligible.
Eastern Water Dragon	✓	✓	✓	Assumed to incidentally ingest soil/sediment during foraging and feeding.
Canns Longnecked Turtle	✓	✓	×	Diet predominantly comprises invertebrates, fish and amphibians. Ingestion of soil/sediment is assumed to be negligible.
Australian Freshwater Crocodile	✓	✓	×	Diet predominantly comprises invertebrates, fish and some small animals. Ingestion of soil/sediment is assumed to be negligible.

RECEPTOR (COMMON NAME)	EXPOSURE PATHWAYS FOR PFAS			
	Ingestion (diet)	Ingestion (Water)	Incidental Ingestion (Soil/Sediment)	Rationale
Predatory Mammals				
Water Rat	✓	✓	✓	As per the terrestrial food web above.
Australian Snubfin Dolphin	✓	✓	✓	Some incidental ingestion of sediment is assumed given it feeds on benthic species.

Notes:

✓ = exposure pathway considered complete and assessed further as part of food web modelling.

✗ = exposure pathway considered incomplete for this receptor and hence not considered further in the ERA.

(1) Pathway not evaluated as the predatory birds selected for evaluation seldom drink water.

(2) Ref: https://www.mdahlem.net/birds/6/blkite.php#food.

(3) Ref: https://www.mdahlem.net/birds/6/swmpharr.php

9.2 CO-LOCATED SAMPLING AND BIOACCUMULATION

Co-located sample analytical results (i.e. samples collected from the same place/time), can be used to indicate that bioaccumulation is occurring to varying levels. This applies to samples for terrestrial and aquatic biota (i.e. soil/earthworms/plants including grasses and grazing flora, sediment/surface water/benthic invertebrates/bivalves).

An evaluation of bioaccumulation has been undertaken utilising the co-located samples collected off-Base (at Bohle River, Town Common, Mundy Creek and Rowes Bay) during the dry season for sediment/surface water and benthic invertebrate (i.e. crustaceans) results. No co-located samples were collected on-Base.

To provide an evaluation of the potential level of bioaccumulation that is occurring, a bioaccumulation factor (BAF) can be estimated for samples that have been co-located. The application of the estimated BAF has been used to provide information on the level of bioaccumulation within aquatic samples collected to date and has not been used to assess the level of risk to the ecosystem.

The potential for bioaccumulation is calculated via the following equation:

$$BAF = Concentration_{\ Biota} / Concentration_{\ Soil\ or\ Sediment}$$

No terrestrial or semi-terrestrial co-located sampling had been undertaken as survey efforts concentrated on particular areas to provide greatest chance of success for target species and were not necessarily specific repeatable sample locations for sediment or surface water, and as such, the potential for bioaccumulation could not be calculated via a BAF approach. Similarly, no co-located samples were collected during the wet season sampling event, or during the marine biota sampling event. Hence, bioaccumulation was not evaluated via a BAF approach for the wet season or the marine biota data.

Table 9.2 below presents the results from co-located sampling of aquatic biota (i.e. crustaceans) and the estimated relevant BAF in sediment/surface water /benthic invertebrates. A BAF has been calculated for benthic invertebrates using the corresponding reported concentration in sediment, as this is the medium that would be their predominant route of exposure to PFAS.

A BAF has not been calculated for fish samples as their exposure is due to a combination of bioaccumulation from dietary and sediment sources, as well as bioconcentration through the gills and/or skin via dissolved phase sources. Hence, evaluating bioaccumulation from sediment intake alone is not considered to accurately represent their exposure. In addition, a BAF has not been calculated for bivalves as these were only collected from BO004 (where PFAS was reported in surface water and sediment during the DSI (WSP, 2018a)) and no detectable concentrations of PFOS or PFOA were recorded.

Aquatic biota sampling for invertebrates was undertaken using a variety of methods including crab pots, cast nets, fyke nets and box traps. At each location multiple organisms were caught and analysed, and therefore multiple results have been reported, with up to 29 at one location (BO007). If <10 detectable concentrations were reported at one location, the average concentration of all detected concentrations was used. If ≥10 samples were reported at one location, the upper confidence limit of the arithmetic mean concentration (95% UCL[1]) was calculated using U.S. EPA's ProUCL software Version 5.1. At BO003, only one detectable PFOS concentration was reported which was therefore used in the BAF calculation. In addition, the sampling site BO001 was not included as only fish were caught at this location and sampling site BO009 was not included as only aquatic plant data was sampled. The calculated benthic invertebrate BAFs are presented for PFOS and PFOA in Table 9.2.

[1] The 95% UCL is the 95 percent upper confidence limit on the arithmetic mean.

Table 9.2 Comparison of co-located sample concentration – aquatic samples

LOCATION	SEDIMENT CONCENTRATION (mg/kg)	BENTHIC INVERTEBRATE CONCENTRATION (mg/kg)	BENTHIC INVERTEBRATE BAF
PFOS			
BO002/SD202 (Bohle River)	0.0031	0.0372(1)	12
BO003/SD203 (Bohle River)	0.0006	0.003(3)	5
BO004/SD204 (Bohle River)	0.0013	ND	–
BO005/SD205 (Town Common)	ND	0.054(3)	–
BO006/SD206 (Town Common)	0.0006	0.0025(2)	4.2
BO007/SD207 (Town Common)	0.0073	0.0267(1)	3.7
BO008/SD208 (Mundy Creek)	0.0011	0.0185(2)	16.8
BO010/SD210 (Rowes Bay)	0.002	0.008(3)	4
PFOA			
BO002/SD202 (Bohle River)	ND	0.0053(2)	–
BO003/SD203 (Bohle River)	ND	ND	–
BO004/SD204 (Bohle River)	ND	ND	–
BO005/SD205 (Town Common)	ND	ND	–
BO006/SD206 (Town Common)	ND	ND	–
BO007/SD207 (Town Common)	0.001	0.0081(2)	8.1
BO008/SD208 (Mundy Creek)	ND	ND	–
BO010/SD210 (Rowes Bay)	0.0004	ND	–

Notes: ND = not detected, NA = no sample collected

(1) Calculated 95% UCL (ProUCL Version 5.1)

(2) Average concentration of all detected concentrations

(3) Result is from a single detectable concentration

All co-located samples in Table 9.2 were collected off-Base and BAFs could not be calculated for all samples, particularly for the compound PFOA, due to the majority of results being reported below laboratory reporting limits. Whilst based on limited data, the calculated BAFs do indicate some bioaccumulation is occurring within benthic invertebrates. However, it does not appear to be dependent on sample location. For example, the two locations that indicate the highest bioaccumulation is occurring, one is a background sample collected from the Bohle River upper estuary (BO002/SD202); whilst the other sample is down-gradient of the Base in Mundy Creek (BO008/SD208). There also does not appear to be a decrease in bioaccumulation away from the source areas. The Bohle River lower estuary sample BO003/SD203, which is the furthest co-located sample collected from the Base, had a calculated BAF of 5, indicating that bioaccumulation is occurring within benthic invertebrates.

The calculated BAFs based on sediment concentrations are considered to be variable and not dependent on location or proximity to source areas. The high variability observed indicates that a range of factors are likely to be influencing the nature and extent of bioaccumulation that occurs within aquatic organisms.

Of note, the estimated BAFs have not been applied beyond this step in the evaluation of potential risks to ecological receptors. They have been presented as part of the ERA as a means of evaluating the level of bioaccumulation that is indicated by the reported concentrations in the aquatic biota samples collected thus far.

9.3 EXPOSURE UNITS AND EXPOSURE POINT CONCENTRATION

9.3.1 EXPOSURE UNITS

The approach of dividing a site up into exposure units is often undertaken as a useful tool for larger sites that require the consideration of different habitats, varying levels of exposure and risk management issues. Exposure and risk estimates are then developed using the data collected for these "exposure units".

The following exposure units have been evaluated as part of this ERA:

- terrestrial and semi-terrestrial environments (sub-divided into soil/terrestrial invertebrate/aquatic invertebrates/amphibians/reptiles); and
- aquatic environments (sub-divided into sediment/surface water/aquatic plants/benthic invertebrates/aquatic vertebrates/amphibians/reptiles).

9.3.2 EXPOSURE POINT CONCENTRATIONS

Exposure point concentrations (EPC) are the concentrations of PFAS in the medium to which the receptors are exposed, at the point of exposure (NEPC 2013). The initial screening of risks was conducted using the maximum PFAS concentrations detected in the exposure unit. Where exposure units contained concentrations exceeding the screening levels, refined estimates of exposure and risk were developed. The refined estimates were developed using an upper estimate of the arithmetic mean concentration, the 95% UCL, where sufficient data was available to calculate reliable UCL concentrations. U.S. EPA's ProUCL software Version 5.1 was used to calculate the UCLs (U.S. EPA 2016). This approach is considered conservative as it will provide a higher estimate of the average.

9.3.2.1 STATISTICAL ANALYSIS

In conducting the statistical analysis, the data for each media was divided up per the identified 'exposure units' (i.e. the area in which samples were collected) to assess risks within the Investigation Area. For the purposes of calculating 95% UCLs, data was divided into on-Base and off-Base areas for each relevant media, as the representative exposure units for the Investigation Area.

The data analysis comprised the following steps:

- ProUCL software to calculate the 95% UCL average, average and standard deviation for each dataset. Where a result was reported as less than detect, half of the limit of reporting (LOR) was adopted as the result.
- A 95% UCL concentration was calculated considering the sample location, i.e. on-Base and off-Base, and the timing of sampling, i.e. dry season and wet season. For comparative purposes, a combined 95% UCL concentration (i.e. incorporating both dry and wet season results) was also calculated.
- For the aquatic biota and semi-terrestrial biota sampling results, the calculated 95% UCLs have excluded the comparative site data and are based on the results reported for impact sites only.
- An assessment of the distribution of the data sets being analysed. For example, where most data points were above the average concentration, data was considered to be positively skewed. Conversely, where most data points were below the average concentration, data was considered to be negatively skewed. Normally distributed data occurs where the data points are evenly distributed either side of the average. Undertaking an assessment of the data distribution provides a more robust understanding regarding the reliability of the 95% UCL estimation.
- An assessment of the uncertainty within and between datasets was undertaken with consideration of the timing of sampling events (i.e. dry and wet season) and the low number of detectable concentrations.

The calculated 95% UCLs are summarised in Table 9.3 below and ProUCL outputs are provided in Appendix F.

Table 9.3 Calculated 95% UCL concentrations

EXPOSURE UNIT	ON-BASE DRY SEASON	ON-BASE WET SEASON	ON-BASE COMBINED	OFF-BASE DRY SEASON	OFF-BASE WET SEASON	OFF-BASE COMBINED
PFOS						
Soil	4.6 mg/kg	0.08 mg/kg(1)	4.4 mg/kg	0.053 mg/kg	–	–
Groundwater	400 µg/L	205 µg/L	477 µg/L(3)	0.44 µg/L	1.3 µg/L	0.6 µg/L
Surface water	37 µg/L	22.1 µg/L	20 µg/L	4.8 µg/L(2)	6.7 µg/L(2)	3.6 µg/L
Sediment	4 mg/kg(3)	34 mg/kg(3)	14 mg/kg(2)	0.05 mg/kg(2)	0.06 mg/kg(2)	0.04 mg/kg
PFOA						
Soil	–	–	0.24 mg/kg	–	–	NC
Groundwater	30.1 µg/L	19 µg/L	21 µg/L	0.03 µg/L	0.08 µg/L	0.039 µg/L
Surface water	1.8 µg/L	3.6 µg/L(2)	2.4 µg/L	0.34 µg/L	0.9 µg/L(2)	0.41 µg/L
Sediment	0.06 mg/kg(3)	0.3 mg/kg(3)	0.12 mg/kg(2)	0.0012 mg/kg(4)	0.003 mg/kg(4)	0.63 mg/kg(4)

(1) Only four on-Base soil samples collected during the wet season event. Hence, the soil concentration is the average of the detectable concentrations reported.

(2) Based on suggested 97.5% UCL.

(3) Based on suggested 99% UCL.

(4) Data negatively skewed based on the 95% UCL due to >50% of the results reported as <LOR. Hence, the 95% UCL is not considered a reliable representation of the data. Therefore, the maximum concentration was adopted as the EPC, refer to Table 9.5.

NC = not calculated since all concentrations were <LOR.

The results presented in Table 9.3 indicate that some seasonal variability may be occurring off-base, will all media reporting an increase in the 95% UCL concentrations of PFOS during the wet season. The same pattern was not apparent however on-Base, whereby the 95% UCL concentration of PFOS in groundwater and surface water decreased during the wet season but in sediment the concentration increased during the wet season.

Four on-Base soil samples were collected during the wet season sampling event and hence, is not a sufficient dataset in which to conduct an assessment of seasonal variations that may occur between the dry and wet seasons. However, the additional soil results collected during April 2018 were from two source areas on-Base (former Fire Training Area NQ0054 and OLAs) and results are comparable between the samples collected during June 2017 and April 2018.

With respect to PFOA concentrations, sediment and groundwater results showed a similar trend as PFOS. PFOA concentrations in surface water increased on-Base (whereas PFOS decreased) and off-Base during the wet season. Given that the reported concentrations for PFOA were consistently either below adopted screening criteria or below the LOR for each media sampled, the variability observed for PFOA in comparison to PFOS is not considered to impact on the EPC selected for quantitative modelling. Based on the results obtained for PFOA, no further consideration via food web modelling was undertaken. However, for completeness, an evaluation of the direct toxicity of PFOA to terrestrial, semi-terrestrial and aquatic biota species was undertaken (refer Section 11.1) via a comparison to the screening criteria (benchmarks) described in Section 8.2.

9.3.3 SUMMARY OF ADOPTED EPC FOR FOOD WEB MODELLING

Tables 9.5 and 9.6 provide a summary of the adopted PFOS EPC used for food web modelling. The EPC was based on either the calculated 95% UCL concentrations (refer Table 9.3), the average or a substituted concentration if no site-specific data available. Specifically, this relates to an absence of site-specific bird tissue data, where, reported PFOS concentrations in chicken eggs was adopted from AECOM (2017). The adopted EPC for chicken eggs was used as a substitute for the consumption of wild birds and/or bird eggs by predatory mammals, reptiles and bird species where smaller birds and bird eggs make up a part of their dietary composition. In the absence of terrestrial vertebrate data (to represent mammals) the EPC was based on reported rabbit tissue data from AECOM (2018). Similarly, in the absence of site-specific terrestrial plant data, available terrestrial plant data from AECOM (2016) was used as a substitute. Reasoning for each of these sources is provided below:

- **Chicken egg dataset**

  The field component of the AECOM (2017) study comprised the collection and analysis for PFAS of chicken egg samples from within the Swartz Barracks (Oakey) Investigation Area. These animals were from populations of chickens that had been directly exposed to PFAS in stock-water sourced from groundwater. Groundwater was their primary source of water. The study inferred an additional exposure pathway from soil, which was the likely result of soil being impacted by PFAS in groundwater through irrigation.

  Whilst the AECOM (2017) study did not assess poultry flesh, the study demonstrated that the egg is a 'sink' for PFAS, and so it is a conservative assumption that PFAS estimates in eggs can be protective of concentrations in flesh.

  Like wild species, the chickens in the study were exposed to PFAS in water and possibly other sources such as soil/sediment. Whilst chickens differ from wild avian species, WSP consider that the AECOM (2017) dataset is a suitable conservative minimum input for the food web modelling in Townsville where avian species are a component.

- **Rabbit/hare dataset**

  Samples of flesh from rabbits / hares were collected by AECOM (2018) as a result of an opportunistic cull that was undertaken within the Base. These animals, having the Base as a large component of their range were likely exposed to PFAS in soil from source areas at the Base through burrowing and consumption of vegetation. They also most likely consumed water from drainage channels which also contained PFAS thereby increasing their body burden.

Although there was not a controlled study into the rabbits/hares by AECOM (2018), pathways of exposure would be similar to Townsville, if not greater given the access to PFAS source areas for the animals at the Base. WSP consider that the AECOM (2018) dataset is a suitable conservative minimum input for the food web modelling in Townsville where terrestrial vertebrates are a component.

— **Terrestrial plant dataset**

Plant sampling in the Townsville Town Common, which comprised mangrove leaves and detritus, were below the limit of reporting and WSP does not consider that this input would be an appropriately conservative input for terrestrial plants in the food web model. The AECOM (2016) terrestrial plant uptake study was a controlled study to assess plant uptake across a range of homegrown produce that was irrigated in glasshouses with PFAS impacted water at concentrations similar to that measured outside the Base but within the Investigation Area. The study identified a preference for PFAS concentration in leafy greens, which has also been observed in the limited plant sampling at residential properties in Townsville. WSP consider that the AECOM (2016) dataset is a suitable conservative minimum input for the food web modelling in Townsville where terrestrial plants are a component.

For soil, on-Base and off-Base dry season results (i.e. 4.6 mg/kg and 0.053 mg/kg) were adopted as the on and off-Base wet season EPCs, given that no wet season soil sampling program was completed off-Base and only four samples were collected on-Base and hence was not considered to represent a sufficient dataset to evaluate potential risks.

Aquatic invertebrate EPCs were based on bivalve and crustacean data (e.g. banana prawn, crab, oyster) collected from various off-Base waterways, and this data was also adopted for the on-Base EPC in the absence of on-Base data. Aquatic vertebrate EPCs were based on statistical analysis of reported PFOS/PFOA concentrations within various fish species, across different trophic levels. Collection sites were all off-Base waterways and so this has been adopted for on-Base EPCs (considered relevant during the wet season). Given the variety of fish eating birds within the Investigation Area; and therefore, the variety of fish that make up their diet, this approach was considered appropriate and the selected EPC may represent an average exposure. Decision factors used to determine appropriate EPCs for use in the ERA are summarised below in Table 9.4.

Table 9.4 Decision factors used to determine EPCs

DECISION FACTOR	EPC TYPE	RATIONALE
<10 samples and <10 detectable concentrations	Average concentration	The average concentration reported was adopted for the relevant media in cases where insufficient data was available to conduct statistical analysis.
≥10 samples and ≥10 detectable concentrations and ≥50% are detectable concentrations	95% UCL	This is considered an appropriately conservative approach (NEPC 2013), provided a sufficient data set is available.
≥10 samples and ≥10 detectable concentrations and <50% are detectable concentrations Or ≥10 samples and <10 detectable concentrations	Average concentration detected	Where the data is skewed, in particularly negatively skewed, the 95% UCL is not considered a reliable representation of the data. Using ProUCL Version 5.1 the arithmetic or gamma adjusted averages were calculated as appropriate.
Non-detect	Not taken forward for quantitative modelling	Where PFOS or PFOA results were all reported as 'not detected' in a sampled environmental media, no further evaluation via quantitative modelling was considered warranted.

Table 9.5 Summary of adopted EPC – terrestrial and semi-terrestrial

AREA	SHALLOW SOIL (0–2 mBGL) (mg/kg DW)	SURFACE WATER (mg/L)	TERRESTRIAL PLANTS(3) (mg/kg W/W)	TERRESTRIAL INVERTEBRATES (EARTHWORMS)(5) (mg/kg DW)	TERRESTRIAL BIOTA (CHICKEN EGGS) (5) (mg/kg W/W)	TERRESTRIAL VERTEBRATES (MAMMALS) (6) (mg/kg W/W)	SEMI-TERRESTRIAL BIOTA (AMPHIBIANS) (mg/kg W/W)	SEMI-TERRESTRIAL BIOTA (REPTILES-ALL) (mg/kg W/W)	SEMI-TERRESTRIAL BIOTA (REPTILES EXCLUDING FRESHWATER SNAKE) (7) (mg/kg W/W)	AQUATIC INVERTEBRATES (BIVAVLES & CRUSTACEAN) (mg/kg W/W)
PFOS – DRY SEASON										
On-Base	4.6(1)	0.037(1)	0.6	0.2	0.006	3	0.103(4)	2.703(1,4)	1.05(1,4)	0.002(2,4)
Off-Base	0.053(1)	0.005(1)	0.009	0.005	0.006	3	0.103 (1)	2.703(1)	1.05(1)	0.002(2)
PFOS – Wet Season										
On-Base	4.6(1)	0.022(1)	0.6	0.2	0.006	3	0.103 (4)	2.703(1,4)	1.05(1,4)	0.002(2,4)
Off-Base	0.053(1)	0.007(1)	0.009	0.005	0.006	3	0.103 (1)	2.703(1)	1.05(1)	0.002(2)

Notes:

(1) Adopted EPCs are the calculated 95% UCL (ProUCL Version 5.1), except the surface water off-Base EPC (wet and dry season), whereby a 97.5% UCL was recommended and adopted.

(2) Average concentration of all detected concentrations.

(3) No site-specific data available. Therefore AECOM (2016) data have been adopted as a substitute. For on-Base, this was the calculated 95%UCL (i.e. 0.6 mg/kg w/w). For off-Base, this was the maximum concentration reported for terrestrial plants collected off-Base (i.e. 0.009 mg/kg w/w).

(4) No on-Base samples were collected, therefore off-Base EPCs have been adopted as a substitute.

(5) No terrestrial invertebrate or terrestrial biota (egg) data has been collected, EPC is based on on-site and off-site data from AECOM (2016).

(6) No site-specific terrestrial vertebrate data available. Adopted EPC (for both on and off-Base) is the rabbit tissue on-Base EPC from AECOM (2018).

(7) Biota data for freshwater snake excluded to evaluate potential risks to the freshwater snake which consumes other reptiles.

Table 9.6 Summary of adopted EPC – aquatic (freshwater and estuarine)

AREA	SEDIMENT (mg/kg DW)	SURFACE WATER (mg/L)	AQUATIC PLANTS (mg/kg W/W)	AQUATIC BIOTA (CHICKEN EGGS) (4) (mg/kg W/W)	SEMI-TERRESTRIAL BIOTA (AMPHIBIANS) (mg/kg W/W)	SEMI-TERRESTRIAL BIOTA (REPTILES-ALL) (mg/kg W/W)	SEMI-TERRESTRIAL BIOTA (REPTILES EXCLUDING FRESHWATER SNAKE) (6) (mg/kg W/W)	AQUATIC INVERTEBRATES (BIVAVLES & CRUSTACEAN) (mg/kg W/W)	AQUATIC VERTEBRATES (FISH) (mg/kg W/W)
PFOS – Dry Season									
On-Base	4.01(1)	0.037(1)	0.0005(2)	0.006	0.103 (2)	2.703(2)	1.05	0.002(2)	0.031(2)
Off-Base	0.052(1)	0.005(1)	0.0005(3)	0.006	0.103 (1)	2.703(1)	1.05	0.002(5)	0.031(1)
PFOS – Wet Season									
On-Base	34.38 (1)	0.022(1)	0.0005(2)	0.006	0.103 (2)	2.703(2)	1.05	0.002(2)	0.031(2)
Off-Base	0.064(1)	0.007(1)	0.0005(3)	0.006	0.103 (1)	2.703(1)	1.05	0.002(5)	0.031(1)

(1) Adopted EPCs are the calculated 95% UCL (ProUCL Version 5.1), except the sediment PFOS on-Base EPC (wet and dry season), whereby a 99% UCL was recommended and adopted. Also, the surface water and sediment off-Base EPC (wet and dry season), whereby a 97.5% UCL was recommended and adopted.

(2) No on-Base samples were collected, therefore off-Base EPCs have been substituted.

(3) Only one detectable concentration was recorded, therefore this has been adopted as the EPC.

(4) Chicken egg data (from AECOM, 2016) has been adopted as an exposure point concentration for bird eating species.

(5) Average concentration of all detected concentrations.

(6) Biota data for freshwater snake excluded to evaluate potential risks to the freshwater snake which consumes other reptiles.

9.4 FOOD WEB MODELLING

9.4.1 INTRODUCTION

Due to the nature, structure and chemical properties of PFAS, the estimation of bioaccumulation using traditional methods (i.e. application of bioaccumulation factors) is not considered appropriate for receptors with complex exposures from multiple sources. Hence, PFAS doses to higher-order receptors (as mg/kg-body weight) were estimated based on modelling a receptor's exposure from ingestion of dietary items (i.e. fish, insects, plant, reptiles, amphibians etc.) and drinking water, as well as incidental ingestion of soil or sediment that may occur during foraging. Diet composition and body weight for each species was identified through available life history information sources outlined in Section 2. Food and water ingestion rates that were not available from life history information, were estimated through methods based on extrapolation from body weight (i.e., Nagy 2001). Incidental soil/sediment ingestion rates were based on values available for receptor species, or species with similar foraging behaviour (e.g., Beyer et al. in U.S. EPA 1993) or from food ingestion rates (i.e., Nagy 2001).

Of note, only PFOS was selected for further evaluation via quantitative food web modelling and where available, concentrations of PFOS in dietary items (i.e. fish, crustaceans, amphibians and reptiles) were based on site-specific measured concentrations.

9.4.2 INTAKE CALCULATIONS

Species specific intakes of PFOS accumulated in food sources/adhered to soil/sediment or dissolved in water were estimated using the following equations (as adopted from Sample et al. 1997):

Equation 1:

$$\text{Intake}_{j} = P_{h}\left(\frac{A}{HR}\left[\sum_{i=1}^{m}\sum_{k=1}^{n} Pik\ (I\ i\ x\ C\ ji)\right]\right)$$

Where:

- Intake $_{j}$ = Total oral exposure (intake) to contaminant (j) (mg/kg/day) intake rate.
- P_h = Proportion of suitable habitat in the contaminated area (assumed to be 100% for the relevant species).
- A = Area contaminated (ha).
- HR = Home range size (ha) of end-point species.
- m = Total number of ingested media (e.g. food, water or soil).
- n = number of media types (i) consumed (unitless).
- P_{ik} = Proportion of type (k) of medium (i) consumed (unitless).
- I_{I} = Ingestion rate for medium (i) (kg/kg body weight/day or L/kg body weight/day).
- C_{ji} = Concentration of contaminant (j) in medium (i) (mg/kg or mg/L).

Note, the **ingestion rate (I_i)** is calculated via several other equation(s) or literature values as detailed below:

Equation 2:

$$I_i = \frac{IngR\ i}{BW}$$

Where:

- I_i = Ingestion rate (g/g body weight/day).
- $IngR_i$ = Ingestion rate of media (i) (soil/water or food source) (g/day).
- BW = Body weight of the organisms for which intake is being calculated (g).

9.4.2.1 FOOD INGESTION RATES – ALTERNATE METHOD

Food ingestion rates for a multitude of Australian species are not readily available in literature. However, ingestion rates for a selection of Australian native species are provided in Nagy (2001). Therefore, where available, food ingestion rates were adopted from Nagy (2001) as detailed in Table 9.7 and Table 9.8. In the absence of available rates by Nagy (2001), food ingestion rates were estimated based on allometric equations published in US EPA (1993) and Nagy (2001). The following equations were used to calculate the food ingestion rate:

Equation 3:

$$IngR_{i\ DW} = awt^{b}$$

Where:

- $IngR_{i\ DW}$= food ingestion rate (g DW/day).
- Wt = representative body weight of receptor species (g WW).
- a = empirical coefficient (all birds = 0.638; all mammals = 0.323; all reptiles = 0.0111). Adopted from Nagy (2001).
- b = empirical coefficient (all birds = 0.685; all mammals = 0.744; all reptiles = 0.92). Adopted from Nagy (2001).

NB: This equation was used for calculating intakes from terrestrial invertebrates, soil and sediment where the estimated concentrations for these food resources are calculated as a dry weight.

Equation 4:

$$IngR_{i\ ww} = aWt^{b}$$

Where:

- $IngR_{i\ ww}$ = food ingestion rate (g WW/day).
- Wt = representative body weight of receptor species (g WW).
- a = empirical coefficient (all birds = 2.065; all mammals = 0.794; all reptiles = 0.0333). Adopted from Nagy (2001).
- b = empirical coefficient (all birds = 0.689; all mammals = 0.773; all reptiles = 0.932). Adopted from Nagy (2001).

NB: This equation (equation 4) was used for calculating intakes from all food sources other than terrestrial invertebrates, soil and sediment; as the estimated concentrations for these food resources are reported as a wet weight.

The following two equations were utilised to calculate the water ingestion rate for each receptor of concern (ROC) as per US EPA (1999). There is no data set available and therefore no equation for relating body weight to water ingestion rate for reptiles or amphibians. As per US EPA (1999), a default water ingestion rate of 0.0001 (L/day) was adopted for reptiles and amphibians.

Equation 5:

$$\text{Water ingestion rate – birds } WI = 0.059 \times wt^{0.67}$$

Where:

- WI = drinking water ingestion (L/day).
- Wt = representative body weight of receptor species (kg).

Equation 6:

$$\text{Water ingestion rate – mammals WI} = 0.099 \text{ x Wt}^{0.90}$$

Where:

- WI = drinking water ingestion (L/day).
- Wt = representative body weight of receptor species (kg).

9.4.3 WILDLIFE EXPOSURE PARAMETERS

Table 9.7 and Table 9.8 summarise the wildlife exposure parameters adopted for food web modelling. Where a receptor was identified to have migratory behaviours, spatial factors were also included in food web modelling to account for a reduced exposure time for these species.

The percentage composition allocated to each dietary item (i.e. plants, invertebrates, reptiles etc.) was based on professional judgement utilising the dietary information for species as per Table 7.3 (terrestrial and semi-terrestrial receptors) and Table 7.4 (aquatic receptors) respectively provided in Section 7.7. For modelling purposes, water consumption was considered to be independent of the dietary composition. Where a receptor was identified to require water, a default parameter of 1 was adopted (i.e. assumed that 100% of their water requirements comes from a water source, as opposed to extracting water from a dietary item).

Based on the expected behaviour of some bird receptor species (primarily predatory bird species) and their potential to move about within the Investigation Area, it has been assumed for modelling purposes that the proportion of available suitable habitat within the Investigation Area is 100%.

Table 9.7 Summary of adopted exposure parameters – terrestrial/semi-terrestrial receptors

RECEPTOR (COMMON NAME)	ASSUMED BODY WEIGHT (g) [(1)]	HOME RANGE (HA) [(2)]	FOOD INGESTION RATE (G OF WET WEIGHT/G BODY WEIGHT/DAY) [(3)]	WATER INGESTION RATE (L/DAY) [(4)]	DIET COMPOSITION (%)[(5)]							
					A	B	C	D	E	F	G	H
Herbivorous Mammals												
Pale Field Rat	80	N/A	0.29 (0.10)	0.01	93	–	–	–	–	–	–	7
Agile Wallaby	21,000	N/A	0.083 (0.025)	1.53	93	–	–	–	–	–	–	7
Invertivorous and Omnivorous Mammals												
Canefield Rat	250	N/A	0.20 (0.066)	0.028	85	10	–	–	–	–	–	5
Lesser Long-Eared Bat	8	N/A	0.56 (0.19)	0.001	–	95	–	–	–	–	–	5
Herbivorous Birds												
Wandering Whistling Duck	750	N/A	0.26 (0.08)	0.049	85	5	–	–	–	–	–	10
Magpie Goose	2,500	N/A	0.18 (0.054)	0.11	90	–	–	–	–	–	–	10
Invertivorous and Omnivorous Birds												
White-browed Crake	52	N/A	0.60 (0.18)	0.008	20	50	–	10	15	–	–	5
Little Pied Cormorant	700	N/A	0.27 (0.08)	0.046	–	60	–	–	35	–	–	5
Pacific Black Duck	1,070	N/A	0.24 (0.07)	0.062	70	20	–	–	-	–	–	10
Predatory Mammals												
Water rat	810	N/A	0.17 (0.06)	0.082	–	50	5	5	20	10	8	2

RECEPTOR (COMMON NAME)	ASSUMED BODY WEIGHT (g) (1)	HOME RANGE (HA) (2)	FOOD INGESTION RATE (G OF WET WEIGHT/G BODY WEIGHT/DAY) (3)	WATER INGESTION RATE (L/DAY) (4)	DIET COMPOSITION (%)(5)							
					A	B	C	D	E	F	G	H
Predatory Reptiles												
Eastern Water Dragon	640	N/A	0.02 (0.007)	0.0001	40	30	5	5	–	18	–	2
Canns Longnecked Turtle	602	N/A	0.02 (0.007)	0.0001	–	50	–	25	25	–	–	–
Freshwater Snake(6)	250	N/A	0.0045(0.0014)	0.0001	-	-	10	60	15	10	5	-
Australian Freshwater Crocodile	55,000	N/A	0.016 (0.005)	0.0001	–	50	10	10	20	5	5	–
Predatory Birds												
Swamp Harrier	740	15570	0.27 (0.08)	N/A	–	10	5	10	5	30	40	–
Brahminy Kite	530	15570	0.29 (0.09)	N/A	–	30	–	–	50	10	10	–
Black Kite	540	15570	0.29 (0.09)	N/A	–	10	30	30	10	10	10	–

Notes for Table 9.7 above

'–' denotes not an applicable component of species specific diet.

N/A = water ingestion rate not calculated for the predatory birds as the species selected seldom drink water.

(1) The assumed body weight for each species is based on the average of the reported weight ranges outlined in Table 7.3, Section 7.7.

(2) The home range of a receptor was only considered where the home range is larger than the assessment area. Where the home range is smaller than the assessment area, no adjustment was made for home range in the exposure calculations, and an annotation of (NA) was provided. For migratory birds, the home range was assumed to be twice the size of the Investigation Area. It is assumed that migratory birds are unlikely to be present in the Investigation Area for most the year.

(3) Food ingestion rates were calculated using the equations presented in Section 9.4.2. A value in parenthesis is the food ingestion rate expressed in g dry weight/g body weight/day. This food ingestion rate was used for the estimation of intakes from environmental media (soil and sediment) as the concentrations in the two media are reported on a dry weight basis.

(4) Ref: US EPA (1999). Water ingestion rates were calculated using the equations presented for water ingestion in Section 9.4.2.

(5) The diet composition of each receptor was based on the information and references presented in notation underneath Table 7.3, Section 7.7. For the purposes of food web modelling, soil ingestion rates were assumed to make up a portion of the total dietary intake for certain species as per the US EPA (1999) methodology.

(6) The food ingestion rate for the freshwater snake is based on the dry matter intake (DMI) and fresh matter intake (FMI) for a common Garter snake as detailed in Nagy (2001). The dry and fresh matter intake values were then used to calculate a representative dry and wet weight food ingestion rates for the freshwater snake per gram of bodyweight per day. The species-specific body weight for a freshwater snake (i.e. 250 g) was adopted for this calculation. Refer to the Calculated Food Ingestion rates provided in Appendix G.

A = Plants (roots, shoots, seeds, nectar)

B = Invertebrates (earthworms, insects)

C = Reptiles

D = Amphibians

E = Fish

F = Mammals

G = Birds

H = Soil

Table 9.8 Summary of adopted exposure parameters – aquatic (estuarine & freshwater) receptors

RECEPTOR (COMMON NAME)	ASSUMED BODY WEIGHT (G) (1)	HOME RANGE (HA) (2)	FOOD INGESTION RATE (G OF WET WEIGHT/G BODY WEIGHT/DAY) (3)	WATER INGESTION RATE (L/DAY) (4)	DIET COMPOSITION (%) (5)							
					A	B	C	D	E	F	G	H
Herbivorous Mammals												
Dugong	420,000	N/A	0.04 (0.01)	22.7	100	-	-	-	-	-	-	-
Invertivorous and Omnivorous aquatic birds												
White-browed Crake	52	N/A	0.6 (0.18)	0.008	20	50	-	10	15	–	–	5
Little Pied Cormorant	700	N/A	0.27 (0.08)	0.046	–	60	–	–	35	–	–	5
Predatory Birds												
Eastern Great Egret	950	15,570	0.25 (0.07)	0.057	–	10	7	8	70	5	–	–
Little Black Cormorant	865	N/A	0.25 (0.08)	0.054	–	20	–	–	80	–	–	–
Predatory Reptiles												
Eastern Water Dragon	640	N/A	0.02 (0.007)	0.0001	40	30	5	5	–	18	–	2
Canns Longnecked Turtle	602	N/A	0.02 (0.007)	0.0001	–	50	–	25	25	–	–	–
Freshwater Snake(6)	250	N/A	0.0045 (0.0014)	0.0001	–	–	10	60	15	10	5	–
Australian Freshwater Crocodile	55,000	N/A	0.016 (0.005)	0.0001	–	50	10	10	20	5	5	–
Predatory Mammals												
Water Rat	810	N/A	0.17 (0.06)	0.082	–	50	5	5	20	10	8	2
Australian Snubfin Dolphin	124,000	N/A	0.06 (0.016)	7.58	–	30	–	–	60	–	–	10

Notes for Table 9.8 above

(1) The assumed body weight for each species is based on the average of the reported weight ranges outlined in Table 7.4, Section 7.7.

(2) The home range of a receptor was only considered where the home range is larger than the assessment area. Where the home range is smaller than the assessment area, no adjustment was made for home range in the exposure calculations, and an annotation of (NA) was provided. For migratory birds, the home range was assumed to be twice the size of the Investigation Area. It is assumed that migratory birds are unlikely to be present in the Investigation Area for most the year.

(3) Food ingestion rates were calculated using the equations presented in Section 9.4.2. A value in parenthesis is the food ingestion rate expressed in g dry weight/g body weight/day. This food ingestion rate was used for the estimation of intakes from environmental media (soil and sediment) as the concentrations in the two media are reported on a dry weight basis.

(4) Ref: US EPA (1999). Water ingestion rates were calculated using the equations presented for water ingestion in Section 9.4.2.

(5) The diet composition of each receptor was based on the information and references presented in notation underneath Table 7.4, Section 7.7. For the purposes of food web modelling, soil/sediment ingestion rates for certain species were assumed to make up a portion of the total dietary intake as per the US EPA (1999) methodology.

(6) The food ingestion rate for the freshwater snake is based on the dry matter intake (DMI) and fresh matter intake (FMI) for a common Garter snake as detailed in Nagy (2001). The dry and fresh matter intake values were then used to calculate a representative dry and wet weight food ingestion rates for the freshwater snake per gram of bodyweight per day. The species-specific body weight for a freshwater snake (i.e. 250 g) was adopted for this calculation. Refer to the Calculated Food Ingestion rates provided in Appendix G.

A = Plants (aquatic plants – samphire, seagrass, mangroves)
B = Invertebrates (aquatic benthic invertebrates (i.e. prawns and mud crabs))
C = Reptiles
D = Amphibians
E = Fish
F = Mammals
G = Birds
H = Sediment

10 TOXICITY ASSESSMENT

This section outlines the toxicity thresholds/criteria that have been adopted to evaluate the potential for toxic effects associated with direct exposure to PFAS impacted environmental media. The values presented in the ERA report are published values and will not be modified by any direct data collected from the Investigation Area.

The environmental concentrations and doses of PFAS contamination that result in no harmful effects, as well as adverse effects, including acute and chronic toxic effects are identified. Acute toxicity values include LC50s and LD50s (i.e., concentrations/doses determined to be toxic to 50 percent of the test populations) and other related endpoints where available. Chronic toxicity values include no-observed-adverse-effect-levels (NOAELs) and lowest-observed-adverse-effect-levels (LOAELs) and other relevant values. The toxicity values have been used to determine the concentration of PFAS that the ecosystem can be exposed to without adverse effects or with adverse effects of a certain magnitude.

10.1 TOXICITY REFERENCE VALUES (TRV)

Toxicity Reference Values (TRVs) for PFAS based on dose (mass of chemical per unit of body weight) were identified for birds, mammals and reptiles based on the results of a literature search and review of other available sources. The TRVs were used in the risk characterisation step to evaluate where a potential for an elevated risk may exist, by comparing the relevant TRVs against the total intake doses for bird, mammal and reptile receptors, calculated from the food web modelling (Section 0).

There are two methods for developing TRVs for ecological receptors:

- For well-studied chemicals, a range of high quality dose-response studies may be available using multiple test species within a single taxonomic class and covering a wide range of doses, exposure durations and sensitive endpoints. In such cases, No Observed Adverse Effect Levels (NOAELs) and Lowest Observed Adverse Effect Levels (LOAELs) can be selected for individual receptor species or receptor groups using several critical studies. In addition, generic NOAELs and LOAELs that are protective of multiple species within a class (i.e. birds and mammals) can be developed by selecting the highest reported NOAEL or the lowest reported LOAEL, or by estimating the geometric mean of the NOAEL and LOAEL values.
- For emerging and less studied chemicals (like the PFAS family), far less qualified studies may be available and are typically limited to a few conventional test species and exposure conditions. The test species may not be directly comparable to the trophic levels and body weights of the receptor groups of concern. In such cases the NOAELs and LOAELs available from the few studies may be modified by uncertainty factors (UFs) as appropriate (although this approach was only applied to determine a NOAEL for avian/reptiles). The lowest of the available NOAELs and LOAELs is then selected as the generic NOAEL and LOAEL that would be protective of an entire species class (i.e. birds and mammals).

Given the relatively few reliable dietary dose-response studies with chronic exposure scenarios for PFAS compounds available, the second method outlined above was adopted (i.e. a single NOAEL and LOAEL value was used to represent all birds or all mammals, regardless of trophic level).

In determining appropriate TRVs for use the approach has utilised the lowest reported NOAEL and LOAEL values reported from results of chronic toxicity studies (refer Table 10.1 below) to represent all avian and all mammalian species, irrespective of taxonomic class or trophic level. The exception to this was PFOA for mammalian species, which was based on the geometric mean of the LOAEL and NOAEL values from eight studies on mice and rats. The adopted TRVs are based on the same toxicological datasets as Environment Canada (2017) in their recent derivation of the *Draft Federal Environmental Quality Guidelines for PFOS* (Environment Canada 2017). Unlike the approach by Environment Canada (2017), UFs were generally not applied within this ERA, except for adopting an UF of 10 to the avian LOAEL, to determine an NOAEL (due to the relevant toxicity study not deriving a NOAEL).

The approach implemented by Environment Canada included the adoption of a total UF of 100 for both mammalian and avian species for the purpose of deriving Federal Wildlife Dietary Guidelines that are intended to protect both avian and mammalian consumers of aquatic biota. The primary goal of the wildlife guidelines is the protection of **all** life stages of **all** wildlife species, and to be used as a screening tool for the protection of all species and hence are more conservative for that reason. In developing the wildlife guidelines, Environment Canada selected the lowest LOAEL to produce a set of tolerable daily intake values (TDI). The UF of 100 was chosen to account for extrapolation from laboratory to field conditions, and for extrapolation from the observed effects level to a no-effect level (i.e. NOAEL).

The lowest literature LOAEL value is defined as the lowest concentration (or dose) at which there was an observed adverse effect in the test species compared to controls. An NOAEL is defined as the highest experimental dose that is not associated with significant adverse effects in the test species compared to controls. These values are conservative by their very nature and in comparison to other guideline values that are derived using similar principals, in most cases it's the geometric mean of the NOAEL or LOAEL values that are selected to produce a set of TDIs (or TRVs), as an effective approach to represent multiple studies, species and endpoints.

The method for selecting UFs in the ERA varies from the guideline derivation approach described in ANZECC (2000) as the ERA is a Tier II NEPM-compliant risk assessment rather than a Tier I screening exercise developed to be a catch-all for potential future consideration. As such, the simplistic method of a separate UF of 10 to account for each of the intra- and inter-species variability has not been applied in this assessment.

In the context of this ERA, the adoption of the TRVs (excluding UFs, except for the avian NOAEL) are considered to be conservative given they are based on the lowest LOAEL/NOAEL (with the exception of PFOA NOAEL for mammalian); and are being applied in the risk characterisation step as means of evaluating if an elevated risk may be present for a particular species.

No appropriate studies upon which to base reptilian TRVs were available. Like birds and mammals, reptiles and amphibians are potentially exposed to contaminants through their diet (prey). Amphibians and reptiles are considered likely to occur off-Base within the surrounding environments from the Base. It is also plausible that some exposure may occur on-Base, given the Town Common wetland area extends onto a portion of the Base in the west. Ecological risks to reptiles are generally not addressed through direct, quantitative modelling as dose-response data for reptile species are very limited for both conventional toxics and emergent chemicals such as PFAS. In general, reptiles have slower metabolic rates than birds and mammals and it can be expected that they ingest less food. Whilst this may therefore result in less exposure to chemicals in food in comparison to birds and mammals it may also have implications for their ability to excrete PFAS. The mechanism of toxicity for reptiles is not well understood and hence, represents an uncertainty. In the absence of dose-response data currently available for reptiles, the TRVs for birds (avian) was adopted to assess potential exposure risks to reptiles.

Consideration of other PFAS compounds that were reported within the various media was also given in the context of their potential toxicity to ecological receptors, there is however relatively limited information available.

A comparative study for the cumulative effects of 17 different PFAS compounds (included within the current laboratory analytical suite and ranging between 4 and 14 carbons long), was undertaken by Borg et. al. (2013), involving the derivation of hazard indexes for hepatotoxicity and reproductive toxicity (a HI could not be derived for other endpoints due to the lack of toxicological data for some PFAS congeners). Exposure assessment studies were evaluated from indirect exposure via the environment on the general population and occupational exposure, and a literature search conducted on relevant hazard/risk assessments and toxicological data. Based on internal doses (serum/plasma PFAS concentrations), the hepatotoxic and reproductive toxic effects of short and long chain PFAS were relatively similar. The hazard assessment indicated that the potency of the congeners generally increased with carbon chain length. This was similar to previous findings by others that the difference in potency of congeners is likely due to kinetic differences as short-chain congeners are more rapidly excreted than long-chain congeners. PFOS and PFOA affected the immune system and mammary gland development at very low doses and the resulting risk characterisation showed concern for both individuals exposed via the environment and occupationally exposed.

Although not an assessment of the relative toxicity of other PFASs, a review of water monitoring results conducted across Sweden at sites including drinking water supplies, groundwater, surface water sewage treatment plant effluents and landfill leachates (Banzhaf et. al. 2017) found PFOS and PFOA frequently detected in the highest concentrations of the PFAS monitored. A discussion regarding available toxicity information for PFAS compounds other than PFOS and PFOA is provided in Section 10.2.

TRVs were selected with an emphasis on chronic toxicity tests with toxicity endpoints that are relevant to the viability of wildlife populations, such as adverse effects on reproduction and offspring survival.

A literature search was conducted using Science Direct, Springer Link, Organisation for Economic Cooperation and Development's (OECD) PFAS Portal and PFOS hazard assessment websites, U.S. EPA's ECOTOX database (https://cfpub.epa.gov/ecotox/help.cfm?sub=about), and other relevant databases to identify and review the most current ecotoxicological information. In addition, toxicity information identified in other ERAs recently prepared for the Defence program was reviewed, including the AECOM (2016) report for Williamtown titled: *Preliminary Ecological Risk Assessment RAAF Base Williamtown Stage 2B Environmental Investigation* (AECOM 2016).

Table 10.1 below summarises the TRVs adopted for the ERA.

Table 10.1 Summary of adopted avian and mammalian TRVs

ANALYTE	TRV (mg/kg BW/Day)		TOXICITY ENDPOINT	REFERENCE/RATIONALE
	NOAEL	LOAEL		
Avian and reptiles				
PFOS	0.077	0.77	Reproductive endpoints (i.e. reduction in fertility, hatchability and offspring survival, and growth of offspring)	Newsted et al., (2005) study on male and female mallards and bobwhite quail. Lowest LOAEL from the bobwhite quail reproduction study was selected. NOAEL was calculated from the LOAEL based on an uncertainty factor of 10.
PFOA	0.077	0.77	In the absence of TRVs for PFOA, PFOS has been used as a surrogate	
Mammalian				
PFOS	0.1	0.4	Reproductive endpoints in singular and multi-generational studies, including maternal weight gain, litter size and weight, delayed reflexes and physical development.	TRVs were from secondary references selected in review documents; Environment Canada (2006) cite US EPA OPPT AR-2260569 (rat study); RIVM Report (2010) cite Case et al., (2001) (rabbit study); Stahl et al., (2011) cite Christian et al., (1999) (rat study); and Dietz et al., (2015) cite Seed (2000) (rat study). No UFs were applied.

ANALYTE	TRV (mg/kg BW/Day)		TOXICITY ENDPOINT	REFERENCE/RATIONALE
	NOAEL	LOAEL		
PFOA	6.2	7.6	Reproduction and developmental endpoints, including reduction in weight gain, delayed physical development, reduced motor coordination.	Selected from Draft Toxicological Profile for Perfluoroalkyls (ATSDR, 2015), based on several reproductive and developmental studies. TRV is the calculated geometric mean of LOAEL and NOAEL values from eight mammalian studies on mice and rats.

10.2 OTHER PFAS COMPOUNDS

While much of the literature and information on PFAS compounds included PFOS and PFOA, relatively little toxicological information is available for other PFAS compounds, in particular pertaining to guidance values and chronic studies.

Using the search tools stated above, searches were conducted on PFAS compounds included as part of the analytical suite during the DSI. Some limited information was available for PFBA and PFBS but due to the limited number of subjects, lack of chronic studies and absence of developmental endpoints, mammalian TRVs for these specific compounds were not obtained. In mammals, studies have found PFBS to be much less toxic than PFOS and not as bioaccumulative, but rather being rapidly excreted by the kidneys. The AECOM (2016) report utilised the mammalian TRV for PFOA as a surrogate in the absence of chemical-specific TRVs for PFBS and this approach has been adopted herein. A dietary study on acute and chronic effects of PFBS on the mallard and northern bobwhite quail was available (Newsted, et al., 2008), with a NOAEL for the quail chronic reproduction study considered appropriate (87.8 mg/kg BW/day). An LOAEL of 878 mg/kg BW/day was adopted by multiplying the NOAEL by a factor of 10 as per guidance provided in US EPA (1995) *Great Lakes Water Quality Initiative Technical Support Document for Wildlife Criteria*. Newsted et al. concluded from the study that PFBS in the environment would be unlikely to pose a significant hazard to birds.

A drinking water criterion for PFNA was established by the New Jersey Department of Environmental Protection (NJDEP) in 2015 based on a developmental study of effects of PFNA in mice by Das et al. (2015). This study generated an LOAEL of 1 mg/kg BW/day (which has been adopted), but no NOAEL. The NOAEL for PFNA (0.1 mg/kg BW/day) was calculated from the LOAEL using an uncertainty factor of 10. An appropriate TRV for PFNA was not available in the searches undertaken for avian receptors.

PFHxS is similar in structure to PFOS and appears to have similar properties, being highly bound to serum albumin and the highest concentrations are generally found in liver and kidney (Food Standards Australia New Zealand (FSANZ), 2017). This contributes to its long biological half-life and as with PFOS, the lack of elimination from humans appears to be due to extensive uptake from enterohepatic circulation and resorption back to the blood which slows down excretion. A study of a Swedish community exposed to contaminated drinking water (Li *et al.*, 2017) estimated the half-life of PFHxS to be greater than PFOS and PFOA and confirmed the long persistence of this compound.

A recent evaluation of available human and animal studies undertaken by FSANZ (2017) concluded there were significant deficiencies in available toxicity and epidemiological studies to develop a TRV for PFHxS or perfluoroalkyl compounds as a group. Only one toxicity study on mammalian oral exposure was considered adequate for PFHxS (using potassium PFHxS), (Butenhoff, et al., 2009). However, a LOAEL or NOAEL was not reported or recommended for use. FSANZ recommended the use of the TRV for the sum of PFOS + PFHxS as a conservative interim measure for the evaluation of human health impacts. While a TRV for PFHxS has not been adopted in the ERA, it was evaluated in the HHRA (WSP 2018c) as an additive with PFOS.

A summary of other PFAS compounds detected within the various media and the relative proportion of these other PFAS compounds (excluding PFOS and PFOA) is summarised in Table 10.2.

Of the other PFAS compounds (i.e. excluding PFOS and PFOA), PFHxS was measured at the highest concentration except in biota plant samples, whereby PFPeA was detected at the highest concentrations (and PFHxS was not detected).

The proportion of total PFAS reported as other PFAS compounds were highest in surface water (on- and off-Base), soil (off-Base), and plant biota. While the relative proportion found in fish, amphibian and reptile biota was significantly lower, comprising <10% of the total PFAS concentration.

Further discussion on the potential for cumulative risks from other PFAS compounds is provided in Section 11.1.4.

Table 10.2 Summary of other PFAS compounds reported within the Investigation Area

AREA	ENVIRONMENTAL MEDIA	NUMBER OF OTHER PFAS COMPOUNDS DETECTED*	MAX. DETECTED CONCENTRATION OF OTHER PFAS COMPOUND (mg/kg)	SUM OF OTHER DETECTED PFAS (BASED ON MAX. CONCENTRATIONS) (mg/kg)	MAX. DETECTED PFOS CONCENTRATION (mg/kg)	% OF TOTAL PFAS CONCENTRATION COMPRISED OF OTHER PFAS COMPOUND*
On-Base	Soil	23	26.9 (PFHxS)(1)	69.86	73.2	40.1%
	Sediment	21	0.737 (PFHxS)	1.151	5.12	20.8%
	Surface water	15	26.8 (PFHxS)	57.62	48.1	62.7%
Off-Base	Soil	5	0.0026 (PFHxS)	0.0046	0.0033	75.2%
	Sediment	12	0.0234 (PFHxS)	0.0349	0.187	17.4%
	Surface water	9	16.0 (PFHxS)	33.85	14.1	65.8%
	Biota (plant)	4	0.004 (PFPeA)	0.004	0.0005	88.9%
	Biota (bivalve)	0	–	–	ND	-
	Biota (crustacean)	26	0.141 (PFHxS)	0.309	0.080	40.6%
	Biota (fish)	14	0.074 (PFHxS)	0.238	0.267	4.1%
	Biota (amphibian)	8	0.069 (PFHxS)	0.120	0.574	8.7%
	Biota (reptile)	9	0.217 (PFHxS)	0.417	14.9	3.2%

Notes:

*Compounds other than PFOS and PFOA

(1) (PFHxS) – indicates the PFAS compound other than PFOS and PFOA which reported the highest concentration and contributed to the total PFAS result.

ND = not detected

11 RISK CHARACTERISATION

The risk characterisation step of the ERA assesses the potential risk to ecological health from exposure to a selected chemical of concern. The process combines the estimated exposure/intake and the toxicity information (i.e. TRVs) to evaluate where an elevated risk may be present for a particular trophic level.

The risk characterisation step presented herein comprises two components:

1. An evaluation of direct toxicity to lower order species (i.e. plants, terrestrial/aquatic invertebrates and fish). This was undertaken via a comparison of the reported PFAS concentrations to a screening benchmark (criteria). This is outlined in Section 11.1; and
2. Potential risks to higher order species were evaluated via:
   a. A combination of direct toxicity impacts for available biota tissue data. Quantitative food web modelling was then undertaken for the selected bird, reptile and mammal species, for both terrestrial/semi-terrestrial and aquatic food webs, to determine a total PFOS intake for each receptor (based on dietary consumption).
   b. A comparison of the modelled intakes against the adopted TRVs was then undertaken to assess if a potential elevated risk may exist from dietary exposure, refer to Section 11.2.

11.1 DIRECT TOXICITY TO LOWER ORDER SPECIES

This section evaluates the potential for direct toxicity to occur in lower order species (i.e. plants, terrestrial and aquatic invertebrates and fish) which are the most highly exposed to impacts within environmental media, as a result of PFAS in soil, sediment and/or surface water.

11.1.1 TERRESTRIAL SPECIES

A summary of the soil concentrations of PFOS and PFOA within the Investigation Area and its potential for direct toxicity to terrestrial and semi-terrestrial species is provided in Table 11.1 below.

Table 11.1 Summary of soil concentrations and potential for direct toxicity to terrestrial and semi-terrestrial species

AREA	NUMBER OF SAMPLES COLLECTED (n)	MAXIMUM DETECTED CONCENTRATION (mg/kg)	AVERAGE DETECTED CONCENTRATION (mg/kg)	SCREENING BENCHMARK (mg/kg)	POTENTIAL FOR IMPACT
PFOS – DRY SEASON					
on-Base	121	**73.2**	**1.81**	0.01	Possible
off-Base	57	**0.511**	**0.0135**		Possible
PFOA – DRY SEASON					
on-Base	121	4.61	0.111	10*	Unlikely
off-Base	57	0.0086	–		Unlikely
PFOS – WET SEASON					
on-Base	4	**0.301**	**0.0847**	0.01	Possible
PFOA – WET SEASON					
on-Base	4	0.0084	0.0032	10*	Unlikely

Notes:

Bold indicates exceedance of adopted screening benchmark

*The screening value for 'Public open space' has been adopted in the absence of other PFOA values

Screening values: 0.01 mg/kg (soil ingestion by secondary consumer); 10 mg/kg (direct toxicity to terrestrial species)

An evaluation of the soil concentrations and their potential for direct toxicity to terrestrial species, indicates a possible direct toxic impact for species located on-Base and off-Base from exposure to PFOS in soil (0–2.0 mBGL) based on the dry season data. There is also a possible direct toxic impact for species located on-Base during the wet season although this is based on only four sample results available. This is based on both the maximum detected PFOS concentration and the average concentration to be above the adopted screening benchmark. Further evaluation of semi-terrestrial species and the likelihood for direct toxicity impacts to be occurring is provided in Section 11.1.2.

The maximum detected concentration of PFOS on-Base from wet season sampling also indicates a possible direct toxic impact to terrestrial/semi-terrestrial species. However, this was based on only four surface samples collected during the wet season sampling event. Reported PFOA concentrations (on-Base and off-Base) do not indicate a potential direct toxic impact for terrestrial species, with all concentrations reported to be below adopted screening benchmarks.

11.1.2 AQUATIC BIOTA SPECIES

11.1.2.1 DIRECT TOXICITY FROM SURFACE WATER AND SEDIMENTS

Table 11.2 below summarises the concentrations of PFOS and PFOA within surface water (on-Base and off-Base) compared against the adopted screening benchmark, considering 95% protection levels for freshwater. The screening benchmark, derived for freshwater protection, has been adopted for marine and estuarine waters as no Australian data were available to derive specific marine/estuarine ecosystem criteria.

Table 11.2 Summary of surface water concentrations and potential for direct toxicity to aquatic (freshwater, estuarine and marine) species

AREA	NUMBER OF SAMPLES COLLECTED (n)	MAXIMUM DETECTED CONCENTRATION (µg/L)	AVERAGE DETECTED CONCENTRATION (µg/L)	SCREENING BENCHMARK (µg/L)	POTENTIAL FOR TOXICITY
PFOS – Dry Season					
On-Base	13	**48.1**	**9.79**	0.13	Possible
Off-Base	31	**14.1**	**1.79**		Possible
PFOA – Dry Season					
On-Base	13	3.0	0.627	220	Unlikely
Off-Base	31	1.18	0.306		Unlikely
PFOS – Wet Season					
On-Base	40	**62.0**	**13.52**	0.13	Possible
Off-Base	30	**18.4**	**1.89**		Possible
PFOA – Wet Season					
On-Base	40	14.1	1.23	220	Unlikely
Off-Base	30	2.68	0.248		Unlikely

Note: **Bold** indicates exceedance of adopted screening benchmark

Based on reported maximum and the average detected surface water concentrations for PFOS during both the dry and wet seasons, there is a potential risk for direct toxicity to aquatic species both on-Base and off-Base. PFOA concentrations on-Base and off-Base for both seasons did not exceed the adopted screening benchmarks and therefore direct toxicity to aquatic species from this compound is considered unlikely. Further evaluation of PFOS concentrations in aquatic biota is provided below in Table 11.4, which summarises the potential for direct toxicity based on aquatic biota tissue results.

Table 11.3 summarises the reported sediment concentrations from on-Base and off-Base locations and comparison against the adopted screening benchmark.

Table 11.3 Summary of sediment concentrations and potential for direct toxicity to aquatic species

AREA	NUMBER OF SAMPLES COLLECTED (n)	MAXIMUM DETECTED CONCENTRATION (mg/kg)	AVERAGE DETECTED CONCENTRATION (mg/kg)	SCREENING BENCHMARK (mg/kg)	POTENTIAL FOR TOXICITY
PFOS – Dry Season					
On-Base	16	**5.12**	**0.568**	0.01	Possible
Off-Base	33	**0.187**	**0.0206**		Possible
PFOA – Dry Season					
On-Base	16	0.0826	0.0105	10*	Unlikely
Off-Base	33	0.0012	0.00072		Unlikely
PFOS – Wet Season					
On-Base	26	**80.2**	**3.649**	0.01	Possible
Off-Base	31	**0.205**	**0.0209**		Possible
PFOA – Wet Season					
On-Base	26	0.625	0.0620	10*	Unlikely
Off-Base	31	0.0033	0.0011		Unlikely

Note: **Bold** indicates exceedance of adopted screening benchmark

*The screening value for 'Public open space' has been adopted in the absence of other PFOA values

Screening values: 0.01 mg/kg (soil ingestion by secondary consumer); 10 mg/kg (direct toxicity to terrestrial species)

Based on the maximum and average detected concentrations for both the dry and wet seasons, there is a possible direct toxicity risk to benthic invertebrates from exposure to PFOS in sediment on-Base and off-Base. The reported concentrations of PFOA for both seasons do not indicate a direct toxicity risk to benthic invertebrates. Further evaluation of PFOS concentrations in aquatic biota is provided below in Table 11.4, which summarises the potential for direct toxicity based on aquatic biota tissue results.

11.1.2.2 DIRECT TOXICITY – AQUATIC BIOTA TISSUE SAMPLES

PFOS concentrations reported in fish and crustacean tissue from the Investigation Area have been evaluated against the bird and mammalian criteria for the consumption of aquatic biota as provided in the NEMP (January 2018). Table 11.4 summarises the reported PFOS concentrations in aquatic biota samples and its potential for direct toxicity.

Table 11.4 Summary of aquatic biota tissue PFOS concentrations and potential for direct toxicity to aquatic (freshwater, estuarine and marine) species

AREA	NUMBER OF SAMPLES COLLECTED (n)	MAXIMUM DETECTED CONCENTRATION (µg/kg)	AVERAGE DETECTED CONCENTRATION (µg/kg)	SCREENING BENCHMARK[1] (µg/kg ww)	POTENTIAL FOR TOXICITY
Bohle River					
Fish (Whole)	13	**152**	**49.4**	**4.6 – mammals (consumption of aquatic biota)** 8.2 – birds (consumption of aquatic biota)	Possible
Fish (Liver)	20	**45**	**10.2**		Possible
Fish (Flesh)	21	**35**	**10.6**		Possible
Crustaceans (Whole)	1	**59**	–		Possible
Crustaceans (Flesh)	21	**6**	1.4		Possible
Crustaceans (Liver)	12	**80**	**33**		Possible
Molluscs (Oyster)	2	ND[2]	–		Unlikely
Mundy Creek (Drains from the Base into Rowes Bay)					
Fish (Whole)	8	**38**	**19.4**	**4.6 – mammals (consumption of aquatic biota)** 8.2 – birds (consumption of aquatic biota)	Possible
Fish (Flesh)	1	1	–		Unlikely
Fish (Liver)	1	**62**	–		Possible
Crustaceans (Whole)	1	**36**	–		Possible
Crustaceans (Flesh)	2	1	–		Unlikely
Rowes Bay					
Fish (Whole)	0	–	–	**4.6 – mammals (consumption of aquatic biota)** 8.2 – birds (consumption of aquatic biota)	–
Fish (Flesh)	33	2	2		Unlikely
Fish (Liver)	27	**184**	**27.0**		Possible
Crustaceans (Whole)	0	–	–		–
Crustaceans (Liver)	6	**11**	**5.3**		Possible
Crustaceans (Flesh)	5	4	1.3		Unlikely

AREA	NUMBER OF SAMPLES COLLECTED (n)	MAXIMUM DETECTED CONCENTRATION (µg/kg)	AVERAGE DETECTED CONCENTRATION (µg/kg)	SCREENING BENCHMARK[1] (µg/kg ww)	POTENTIAL FOR TOXICITY
Three Mile Creek (Drains from the Base into Rowes Bay)					
Fish (Whole)	5	**19**	**10.4**	**4.6 – mammals (consumption of aquatic biota)** 8.2 – birds (consumption of aquatic biota)	Possible
Crustaceans (Flesh)	3	ND	–		NA
Town Common					
Fish (Whole)	15	**267**	**103**	**4.6 – mammals (consumption of aquatic biota)** 8.2 – birds (consumption of aquatic biota)	Possible
Fish (Flesh)	5	2	2		Unlikely
Fish (Liver)	14	**983**	**194**		Possible
Crustaceans (Whole)	1	**50**	–		Possible
Crustaceans (Flesh)	24	**54**	3.5		Possible
Crustaceans (Liver)	12	**47**	**27**		Possible
Alligator Creek (Comparative Site)					
Fish (Whole)	2	ND	–	**4.6 – mammals (consumption of aquatic biota)** 8.2 – birds (consumption of aquatic biota)	Unlikely
Fish (Flesh)	11	ND	–		Unlikely
Crustaceans (Whole)	1	ND	–		Unlikely
Crustaceans (Flesh)	11	ND	–		Unlikely
Althaus Creek (Comparative Site)					
Fish (Whole)	9	ND	–	**4.6 – mammals (consumption of aquatic biota)** 8.2 – birds (consumption of aquatic biota)	Unlikely
Fish (Flesh)	35	**6**	–		Possible
Crustaceans (Flesh)	14	ND	–		Unlikely
Molluscs (Oyster)	2	ND	–		Unlikely

AREA	NUMBER OF SAMPLES COLLECTED (n)	MAXIMUM DETECTED CONCENTRATION (µg/kg)	AVERAGE DETECTED CONCENTRATION (µg/kg)	SCREENING BENCHMARK(1) (µg/kg ww)	POTENTIAL FOR TOXICITY
Gordon Creek (Comparative Site)					
Fish (Whole)	9	2	1.5	**4.6 – mammals (consumption of aquatic biota)** 8.2 – birds (consumption of aquatic biota)	Unlikely
Fish (Flesh)	2	ND	–		Unlikely
Crustaceans (Whole)	1	2	–	**4.6 – mammals (consumption of aquatic biota)** 8.2 – birds (consumption of aquatic biota)	Unlikely
Crustaceans (Flesh)	3	ND	–		Unlikely
Molluscs (Oyster)	1	ND	–	**4.6 – mammals (consumption of aquatic biota)** 8.2 – birds (consumption of aquatic biota)	Unlikely
Sandfly Creek (Comparative Site)					
Fish (Whole)	1	1	–	**4.6 – mammals (consumption of aquatic biota)** 8.2 – birds (consumption of aquatic biota)	Unlikely
Fish (Flesh)	15	ND	–		Unlikely
Crustaceans (Flesh)	6	ND	–		Unlikely

Notes:

ND – non-detect

NA – not applicable as no result reported for biota type.

(1) Ref: NEMP (January 2018).

The maximum detected concentration and average detected PFOS concentrations reported in aquatic biota from the Bohle River, Mundy Creek, Town Common, Rowes Bay, and Three Mile Creek indicate there is a potential for direct toxicity to mammals and birds who consume aquatic biota including fish and crustaceans. Aquatic biota samples collected from comparative sites (outside the Investigation Area) did not indicate a direct toxicity risk to aquatic (freshwater and estuarine) species, except for Althaus Creek, that reported a maximum fish flesh sample (6 µg/kg) above the screening benchmark for mammals and the consumption of aquatic biota.

Table 11.5 summarises the concentrations of PFOS reported within aquatic plant tissue samples collected off-Base and provides a comparison to the adopted screening benchmark to assess the potential for toxicity to aquatic plants. The screening benchmark has been adopted from the classification system for marine sediments utilising the concentration with no toxic effects (Norwegian Pollution Control Authority, 2008).

Table 11.5 Summary of aquatic plant tissue concentrations and potential for direct toxicity to aquatic plants

AREA	NUMBER OF SAMPLES COLLECTED (n)	MAXIMUM DETECTED CONCENTRATION (µg/kg)	AVERAGE DETECTED CONCENTRATION (µg/kg)	SCREENING BENCHMARK(1) (µg/kg)	POTENTIAL FOR TOXICITY
PFOS – Off-Base					
Within Investigation Area					
Mangrove	24	ND	–	220	Unlikely
Samphire	5	0.5	–		Unlikely
Sargassum	3	ND	–		Unlikely
Seagrass	8	ND	–		Unlikely
Outside Investigation Area (Comparative Sites)					
Mangrove	10	ND	–	220	Unlikely
Samphire	2	ND	–		Unlikely
Sargassum	4	ND	–		Unlikely
Seagrass	4	ND	–		Unlikely

(1) Ref: Norwegian Pollution Control Authority (2008).

PFOS concentrations within plant tissue samples were less than the laboratory LOR except for one sample collected from the Town Common which reported a detectable concentration of 0.5 µg/kg. This indicates that based on the reported PFOS concentrations there is unlikely to be a direct toxicity risk to aquatic plants located within and outside the Investigation Area.

11.1.3 SUMMARY OF ECOLOGICAL RISKS FROM PFOS

The potential ecological risk to lower order species from exposure to PFOS across various environmental media is summarised as follows:

SOIL

The reported soil concentrations of PFOS on-Base may pose a toxicity risk to freshwater life from PFOS originating in soil, leaching to groundwater and subsequently discharging to nearby surface water bodies. The reported soil concentrations off-Base may pose a toxicity risk to secondary consumers via ingestion of soil.

SURFACE WATER

The reported surface water concentrations of PFOS on-Base and off-Base may pose a toxicity risk to aquatic species (based on 95% species protection).

SEDIMENT

The reported sediment concentrations of PFOS on-Base may pose a toxicity risk to freshwater life from PFOS originating in sediment. The reported sediment concentrations off-Base may pose a toxicity risk to secondary consumers via ingestion of sediment.

AQUATIC BIOTA

The reported PFOS concentrations in aquatic biota (fish and crustacean tissue) from the Bohle River, Mundy Creek, Town Common, Rowes Bay, and Three Mile Creek may pose a toxicity risk to mammals and birds who consume aquatic biota. The reported PFOS concentrations in aquatic plant tissue off-Base do not indicate a potential toxicity risk to aquatic plants located within and outside the Investigation Area.

11.1.4 POTENTIAL FOR CUMULATIVE RISKS FROM OTHER PFAS COMPOUNDS

A summary of the other PFAS compounds detected (other than PFOS and PFOA) within various media on-Base and off-Base has been summarised in Table 10.2, Section 10.2.

A wide range of other PFAS compounds have been detected within the Investigation Area and in the case of biota, all PFAS compounds from the suite analysed were detected, noting that the 28-PFAS suite is not the extent of PFAS chemicals that are possible within a 'typical' 3M Lightwater or Ansulite source.

In soil, only three PFAS compounds (MeFOSE, EtFOSA, EtFOSE) were not detected. In groundwater 19 out of 26 'other' PFAS compounds were detected. Within sediment 21 out of 26 'other' PFAS compounds were detected and the five PFAS compounds not detected were PFTeDA, 4:2 FTS, MeFOSA, MeFOSAA, and EtFOSA.

In surface water, there were 11 'other' PFAS compounds that were not detected (PFDoDA, PFTrDA, PFTeDA, MeFOSA, EtFOSA, MeFOSE, EtFOSE, MeFOSAA, EtFOSAA, 4:2 FTS and 10:2 FTS). Within all media the other PFAS compounds were generally only detected where concentrations of PFOS (and PFHxS) were elevated.

Of the other PFAS compounds detected, PFHxS was measured at the highest concentration across all media apart from biota plant samples, whereby PFPeA was detected at the highest concentrations (and PFHxS was not detected). The sum of maximum detected concentrations of other PFAS compounds were more than the maximum PFOS concentration within the following media: surface water (on- and off-Base), soil (off-Base) and biota (plant and crustacean). The maximum detected concentration of PFHxS in surface water (off-Base) and crustacean biota samples was greater than the maximum detected PFOS concentration.

In addition to the above, the maximum detected concentration of PFPeA in plant samples was greater than the detected PFOS concentration. PFPeA is part of the perfluoroalkyl carboxylate group with a structure similar to PFOA, although very little research on the toxicity of PFPeA has been undertaken.

Given the similar mode of action of PFHxS to PFOS and its persistence in the environment (as discussed in Section 10.1), there is the potential that cumulative risks to ecological receptors from exposure to PFAS compounds other than PFOS and PFOA and/or in conjunction with PFOS and PFOA may occur. This includes PFHxS and others however, as indicated little research on the toxicity of other PFAS compounds has been completed to date. Furthermore, some precursors and intermediate breakdown products, although short-lived, may have higher toxicity than the compound that has been assessed and this remains an uncertainty. Hence, cumulative toxicity associated with this group of chemicals is not well understood, nor can the potential risks from exposure to other PFAS compounds be quantified as part of this ERA.

11.2 POTENTIAL RISKS TO HIGHER ORDER SPECIES

11.2.1 DIRECT TOXICITY TO SEMI-TERRESTRIAL SPECIES

A summary of the concentrations of PFOS reported within semi-terrestrial biota collected within and outside the Investigation Area and its potential for direct toxicity to semi-terrestrial species is provided in Table 11.6. The screening benchmark adopted for PFOS was the interim – ecological direct exposure for wildlife diet guideline values.

Table 11.6 Summary of semi-terrestrial biota concentrations and potential for direct toxicity

DIET ITEM	NUMBER OF SAMPLES COLLECTED (n)	MAXIMUM DETECTED CONCENTRATION (µg/kg)	AVERAGE DETECTED CONCENTRATION (µg/kg)	SCREENING BENCHMARK (µg/kg)	POTENTIAL FOR TOXICITY
PFOS – Investigation Area					
Amphibian	43	**574**	**71**	**4.6 (Mammalian Wildlife Diet)** 8.2 (Avian Wildlife Diet)	Possible
Reptile	27	**14,900**	**1,451**		Possible
PFOS – Reference Location					
Amphibian	10	**12**	**6.5**	**4.6 (Mammalian Wildlife Diet)** 8.2 (Avian Wildlife Diet)	Possible
Reptile	4	ND	–		Unlikely

Note: **Bold** and/or underline indicates exceedance of adopted screening benchmark

Based on an evaluation of the concentration of PFOS reported in semi-terrestrial biota there is a possible risk for direct toxicity to mammalian and avian consumers of amphibian and reptile biota within the Investigation Area. The highest concentration of 14,900 µg/kg was detected in a freshwater snake from the Town Common and the maximum amphibian concentration was reported in Rowes Bay. The samples outside the Investigation Area were collected from Alligator Creek, approximately 30 km south-east of the Base. One cane toad sample reported a PFOS concentration of 12 µg/kg exceeding the screening benchmark for a mammalian wildlife diet.

Of note, further evaluation of the reptile species Canns Longnecked turtle and the freshwater snake were undertaken via quantitative modelling given they are both tertiary consumers. Refer to Section 11.2.2 below.

11.2.2 FOOD WEB MODELLING – TOTAL INTAKE ESTIMATES FROM DIETARY EXPOSURE

The following presents and discusses potential risks for bioaccumulation to be occurring to higher trophic levels based on the output of food web modelling. Potential risks associated with multiple complete exposure pathways for the identified receptors are quantitatively assessed using the food web modelling methods as derived by the US EPA. The food web model calculations for food rates and intake does are provided in Appendix G.

Calculated total intake concentrations have been compared to adopted TRVs (refer Section 11.1) to assess the potential for an elevated risk to a trophic level (i.e. primary and secondary consumers to higher order predators) within the Investigation Area. Risks to receptors have been presented based on multiple lines of evidence where data are available (i.e. lower to higher order species).

Modelled intake doses for each receptor are presented in Appendix G.

The cluster bar charts overleaf (Figures 11.1 to 11.6 for terrestrial/semi-terrestrial receptors and Figures 11.7 to 11.12 for aquatic receptors) illustrate the modelled total doses (based on dietary intakes) in comparison to the adopted TRVs for birds, reptiles and mammals. This provides a more detailed assessment and depicts where the modelled intakes sit in comparison to no observable effects to low observable effects (i.e. NOAEL and LOAEL TRVs).

Of note, the modelled intake doses calculated for the dry and wet seasons on-Base are the same for some species. This is due in part to the model being dependent on dietary consumption and therefore, the exposure point concentrations that are adopted/estimated for each dietary component will impact on the resultant dose/intake for each dietary component. For example, for species where incidental soil ingestion forms a part of their diet (such as the Pale Field Rat), since the adopted soil EPC for PFOS on-Base, was the same for the dry and wet season, due to limited data collected during the wet season, the resulting modelled intakes are the same. In addition, as biota sampling has not been undertaken across seasons (i.e. dry and wet), adopted EPCs for aquatic and/or semi-terrestrial biota is the same for both dry and wet seasons, which results in the same intake dose being calculated for species where biota is a component of their dietary intake.

11.2.2.1 TERRESTRIAL/SEMI-TERRESTRIAL RECEPTORS (ON-BASE AND OFF-BASE)

The following charts are provided for mammals, bird and reptile species:

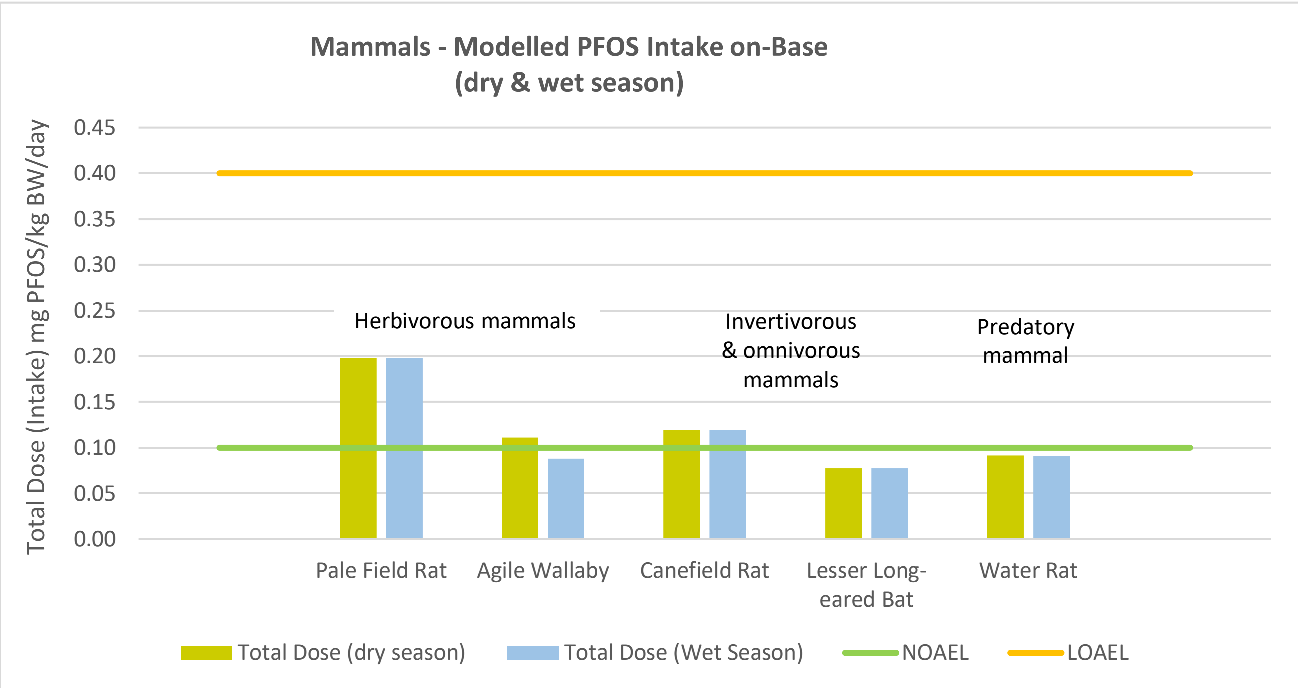


Figure 11.1 Modelled PFOS intake for terrestrial/semi-terrestrial mammals on-Base (dry and wet season results)

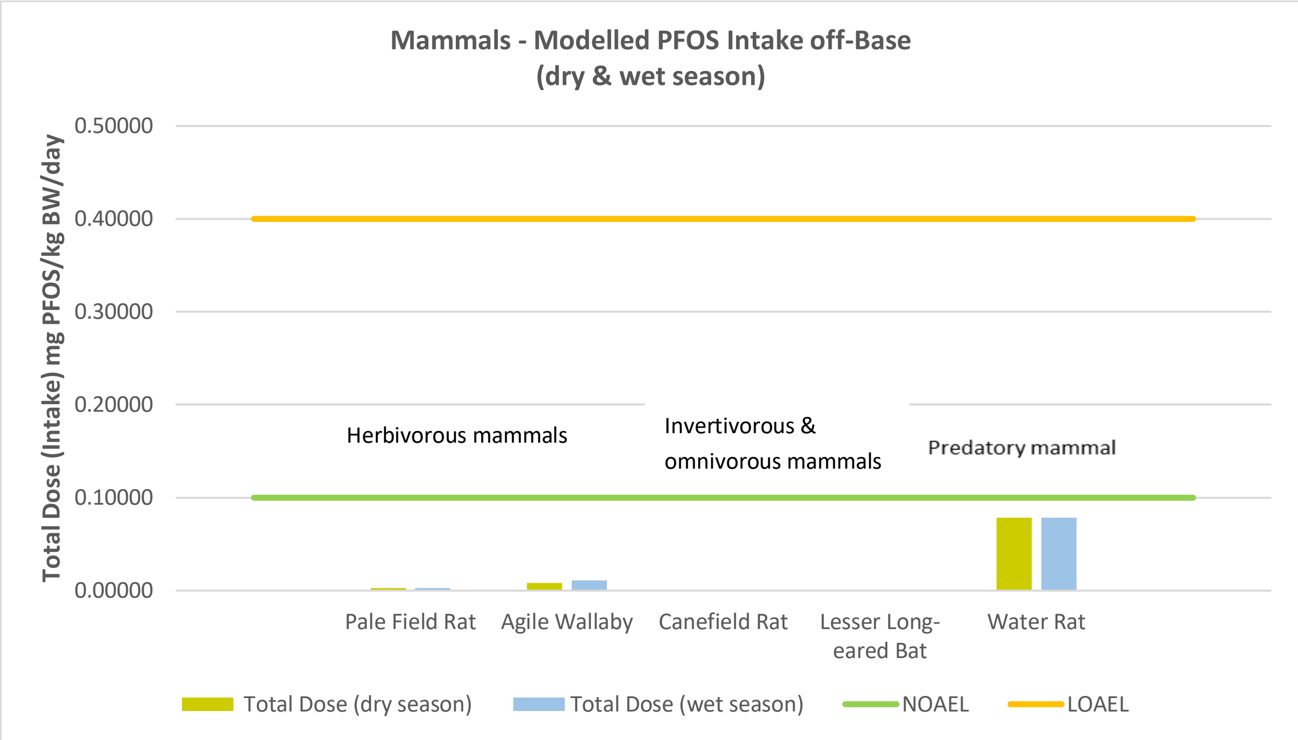


Figure 11.2 Modelled PFOS intake for terrestrial/semi-terrestrial mammals off-Base (dry and wet season results)

Figures 11.1 and 11.2 above indicate that for:

- Herbivorous mammals (on-Base), the total intake dose modelled from dietary exposure is above the NOAEL but below the LOAEL TRVs for both dry and wet seasons for one receptor and the intake dose of the other receptor was below the NOAEL during the wet season only.
- Invertivorous and omnivorous mammals (on-Base), the total intake dose modelled from dietary exposure is above the NOAEL but below the LOAEL TRVs for both dry and wet seasons for one receptor, with the other receptor below both the NOAEL and LOAEL TRVs (for dry and wet seasons).
- Predatory mammals (on-Base), the total intake dose modelled from dietary exposure is below both the NOAEL and LOAEL TRVs for dry and wet seasons.
- All mammal species (off-Base), the total doses modelled from dietary exposure are below both the NOAEL and LOAEL TRVs during the dry and wet seasons.

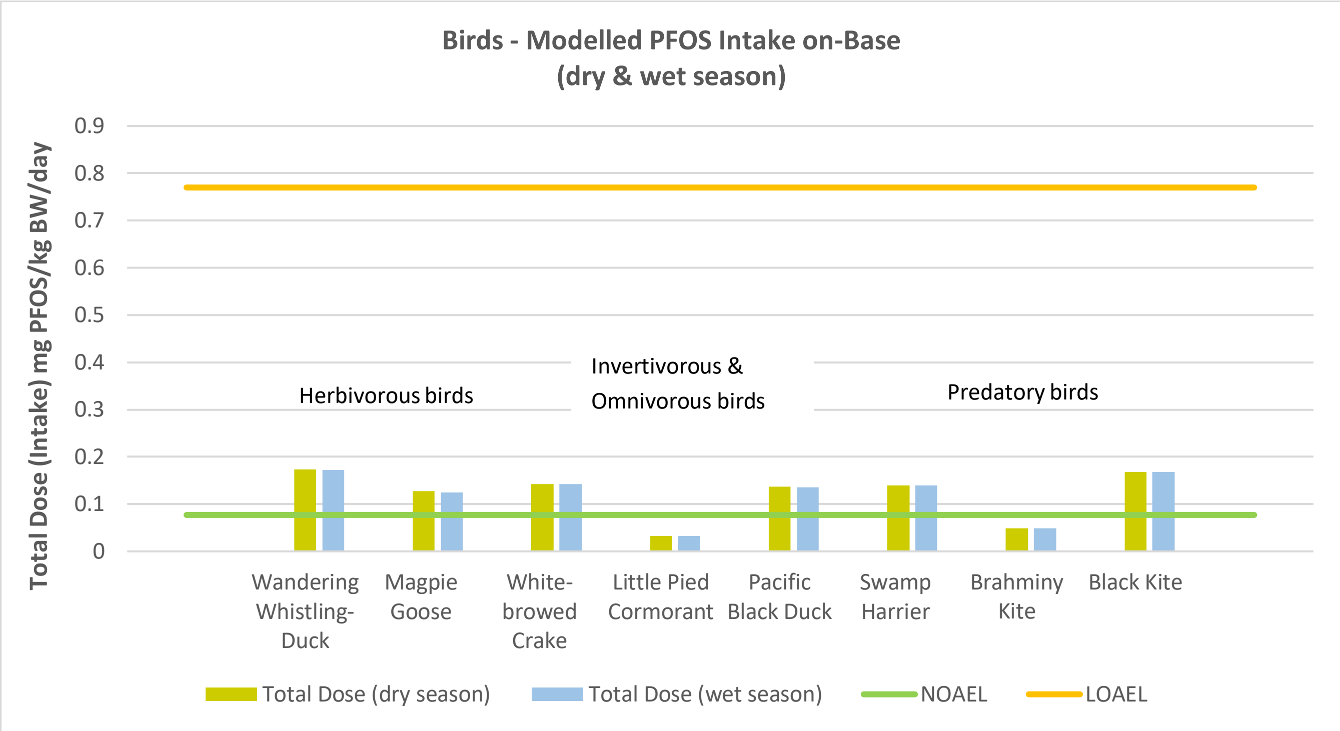


Figure 11.3 Modelled PFOS intake for terrestrial/semi-terrestrial birds on-Base (dry and wet season results)

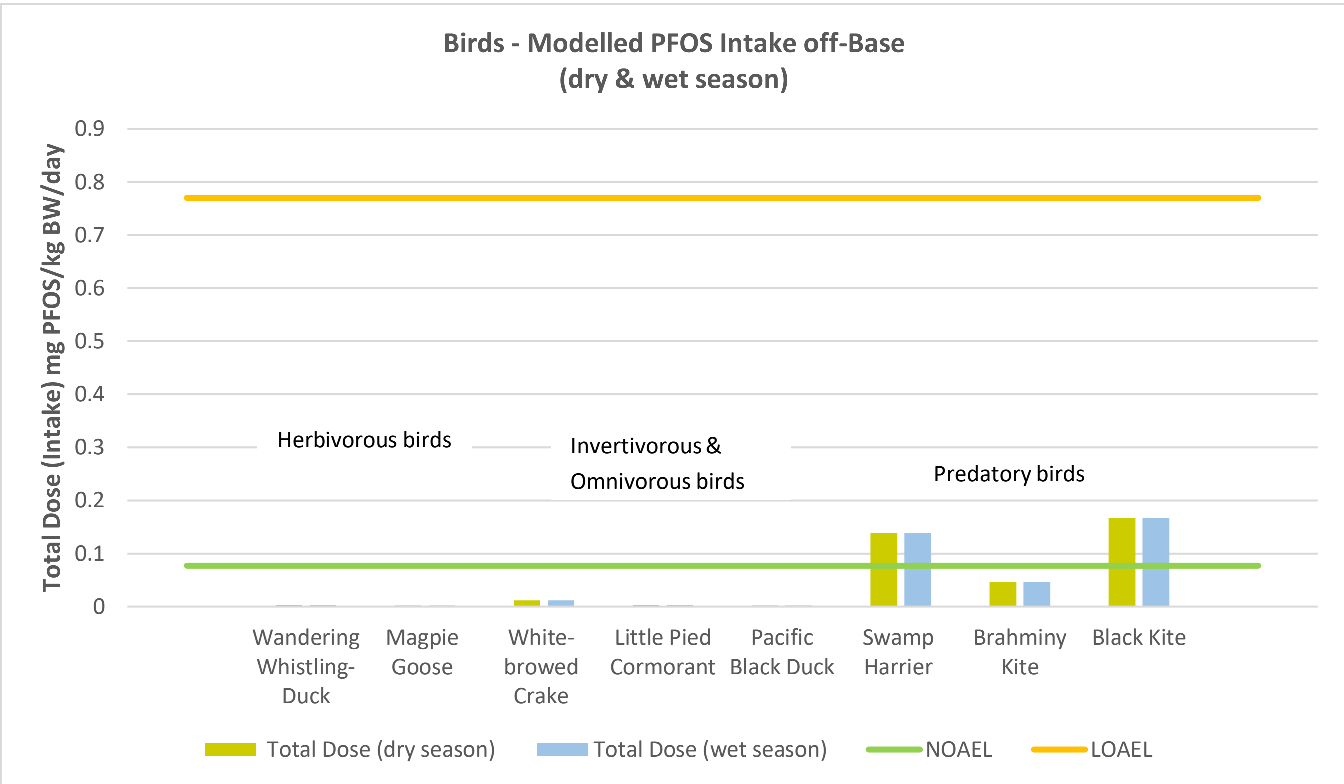


Figure 11.4 Modelled PFOS intake for terrestrial/semi-terrestrial birds off-Base (dry and wet season results)

Figures 11.3 and 11.4 above indicate that for:

- Herbivorous, invertivorous/omnivorous and predatory bird species (on-Base), the total intake dose modelled from dietary exposure, for one or more receptors within each trophic level, is above the NOAEL TRV. However, bird receptor intake doses for each trophic level were below the LOAEL TRV.
- Herbivorous and invertivorous/omnivorous bird species (off-Base), the total intake dose modelled from dietary exposure is below both the NOAEL and LOAEL TRVs for dry and wet seasons.
- Predatory bird species (off-Base), the total intake dose modelled from dietary exposure was above the NOAEL TRV (for at least one species) during dry and wet seasons. However, total intakes were below the LOAEL TRV.

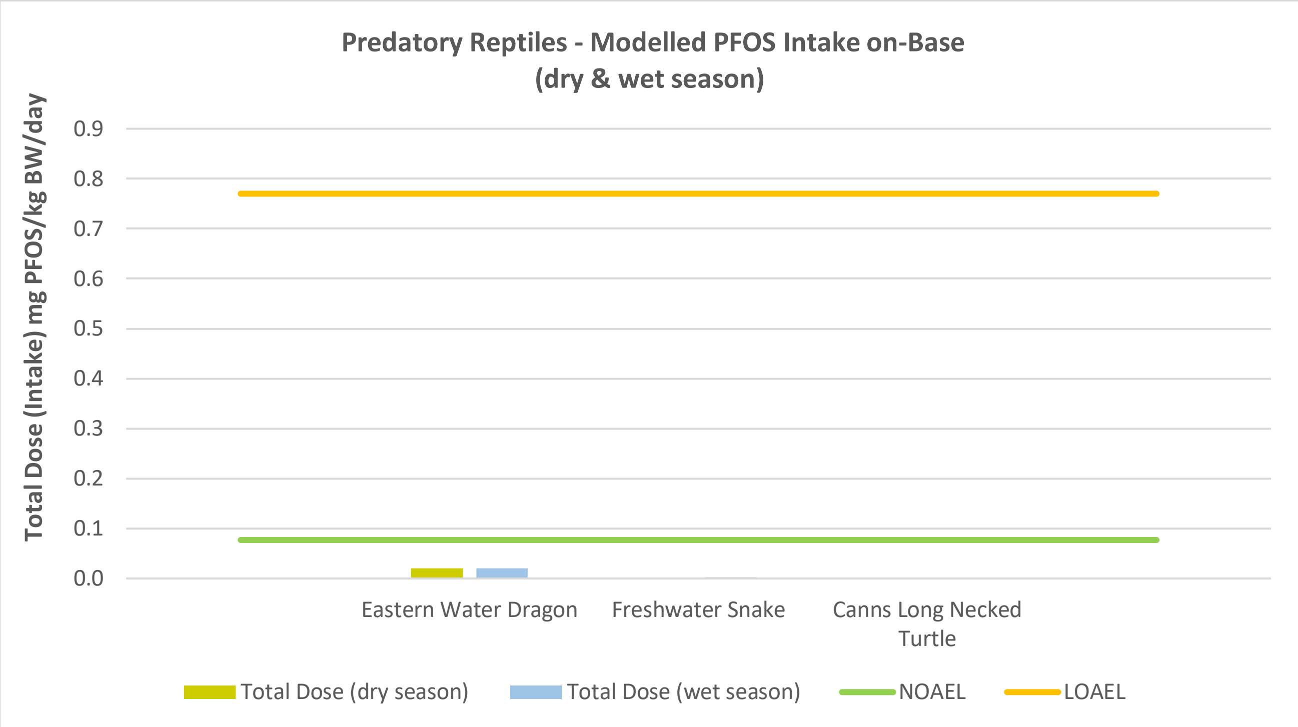


Figure 11.5 Modelled PFOS intake for terrestrial/semi-terrestrial reptiles on-Base (dry and wet season results)

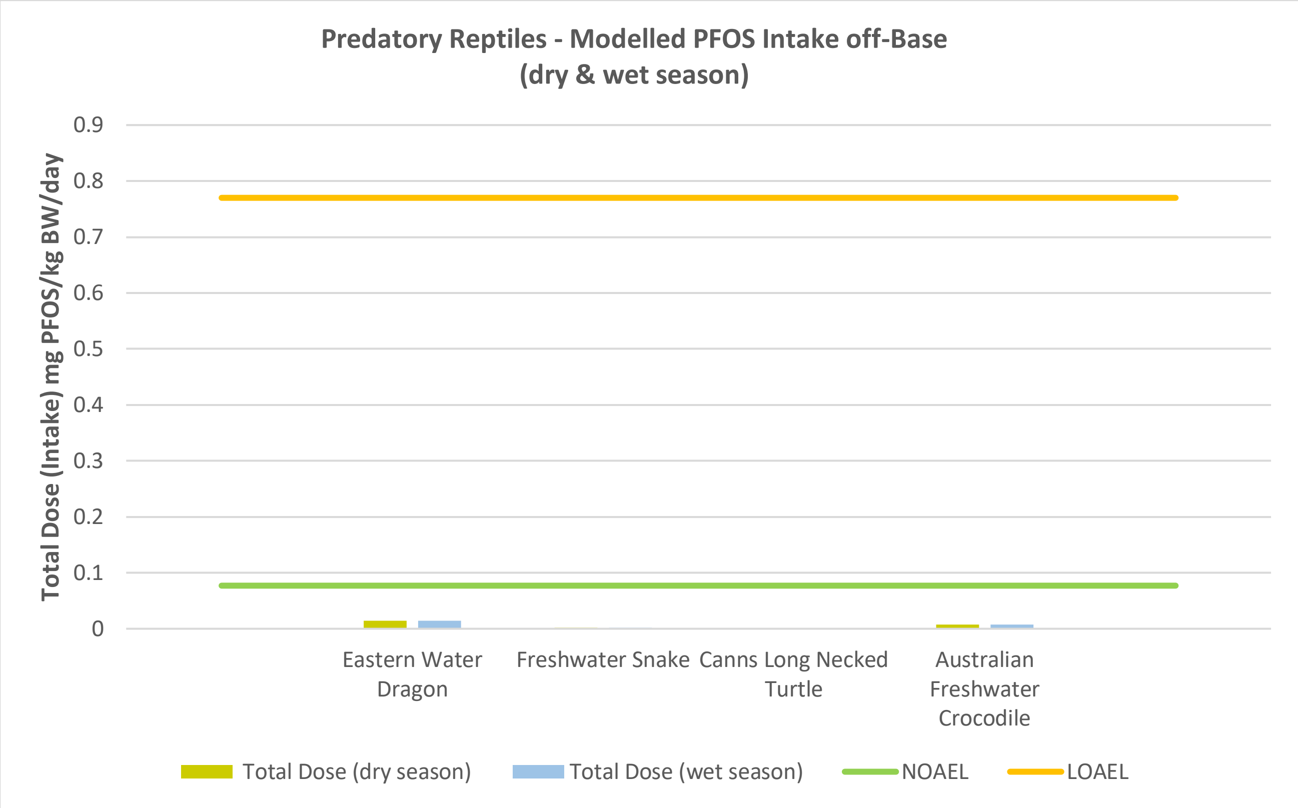


Figure 11.6 Modelled PFOS intake for terrestrial/semi-terrestrial reptiles off-Base (dry and wet season results)

Figures 11.5 and 11.6 above indicate that for:

— Predatory reptiles (on and off-Base), the total intake doses modelled from dietary exposure are below the NOAEL and LOAEL TRVs for dry and wet seasons.

In summary, based on total PFOS intake estimates from dietary exposure, the following terrestrial/semi-terrestrial trophic levels exceed the NOAEL indicating there may be a potential risk for the bioaccumulation of PFOS:

— On-Base: herbivorous mammals, invertivorous and omnivorous mammals, herbivorous birds, invertivorous and omnivorous birds, and predatory birds.
— Off-Base: predatory birds.

No terrestrial/semi-terrestrial trophic levels exceed the LOAEL.

A summary of the risk evaluation for terrestrial/semi-terrestrial species is provided in Table 11.7 below. The potential risk to receptors has been assessed via comparison of the total intake dose to the adopted NOAEL and LOAEL TRVs, i.e. risk is deemed low and acceptable if the total intake dose is below the NOAEL (and LOAEL) or a potential for elevated exposure risk if the total intake dose is greater than the NOAEL (and LOAEL).

Based on the risk evaluation for terrestrial/semi-terrestrial species outlined above there were clear differences in the potential for elevated exposure risk based on location, i.e. on-Base or off-Base for the following trophic levels: herbivorous mammals, invertivorous and omnivorous mammals, herbivorous birds, and invertivorous and omnivorous birds. Larger differences in the total intake doses were noted in these species due to higher exposure point concentrations for on-Base soil, surface water, plants and invertebrates compared with off-Base resulting in a total intake dose greater than the adopted NOAEL TRV. Total intake doses were generally comparable between dry season and wet season across trophic levels as the EPCs for dry season were adopted for wet season (with the exception of surface water) since biota sampling was conducted in the dry (or just prior to the start of the wet season, in the case of the semi-terrestrial sampling) and an insufficient dataset was available for soil during the wet season (see Sections 2.2 and 9.3.3).

Table 11.7 Terrestrial/semi-terrestrial species – risk evaluation

RECEPTOR	TOTAL INTAKE DOSE (MG PFOS/KG BW/DAY)		NOAEL TRV (mg/kg BW/DAY)	LOAEL TRV (mg/kg BW/DAY)	RISK EVALUATION
	on-Base	off-Base			
Herbivorous mammals	0.2 (dry season) 0.2 (wet season)	0.008 (dry season) 0.01 (wet season)	0.1	0.4	Potential for elevated exposure risk - on-Base Low and acceptable for off-Base
Invertivorous & Omnivorous mammals	0.12 (dry season) 0.12 (wet season)	0.002 (dry season) 0.002 (wet season)			Potential for elevated exposure risk - on-Base Low and acceptable for off-Base
Herbivorous birds	0.17 (dry season) 0.17 (wet season)	0.003 (dry season) 0.003 (wet season)	0.077	0.77	Potential for elevated exposure risk – on-Base Low and acceptable for off-Base
Invertivorous & Omnivorous birds	0.14 (dry season) 0.14 (wet season)	0.011 (dry season) 0.011 (wet season)			Potential for elevated exposure risk – on-Base Low and acceptable for off-Base
Predatory mammals	0.092 (dry season) 0.091 (wet season)	0.078 (dry season) 0.078 (wet season)	0.1	0.4	Low and acceptable for on and off-Base
Predatory reptiles	0.02 (dry season) 0.02 (wet season)	0.015 (dry season) 0.015 (wet season)	0.077	0.77	Low and acceptable for on and off-Base
Predatory birds	0.17 (dry season) 0.17 (wet season)	0.17 (dry season) 0.17 (wet season)			Potential for elevated exposure risk – on-Base Potential for elevated exposure risk – off-Base

Notes:

(1) Total intake doses are the highest modelled intakes for a receptor within each trophic level (where more than one receptor was evaluated for a trophic level). Refer Appendix G for individual species modelled intakes.

11.2.2.2 AQUATIC RECEPTORS (ON-BASE AND OFF-BASE)

The following charts are provided for mammals, bird and reptile species:

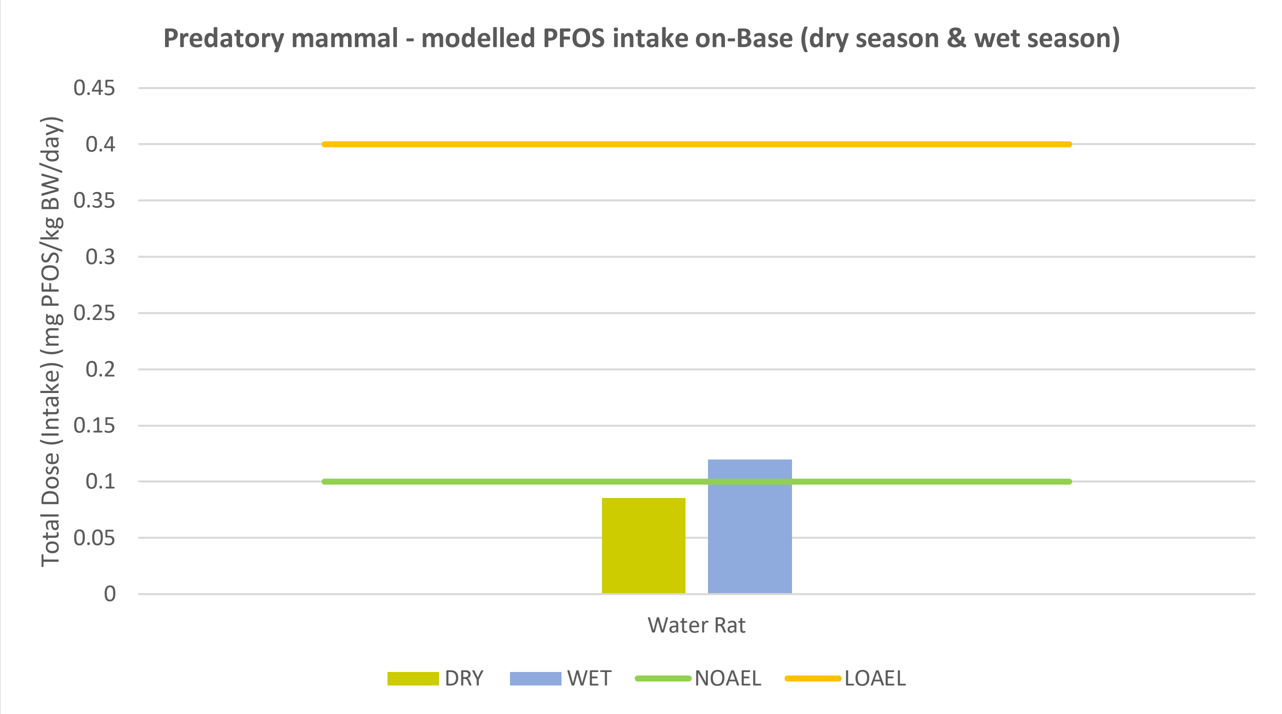


Figure 11.7 Modelled PFOS intake for aquatic mammals on-Base (dry and wet season results)

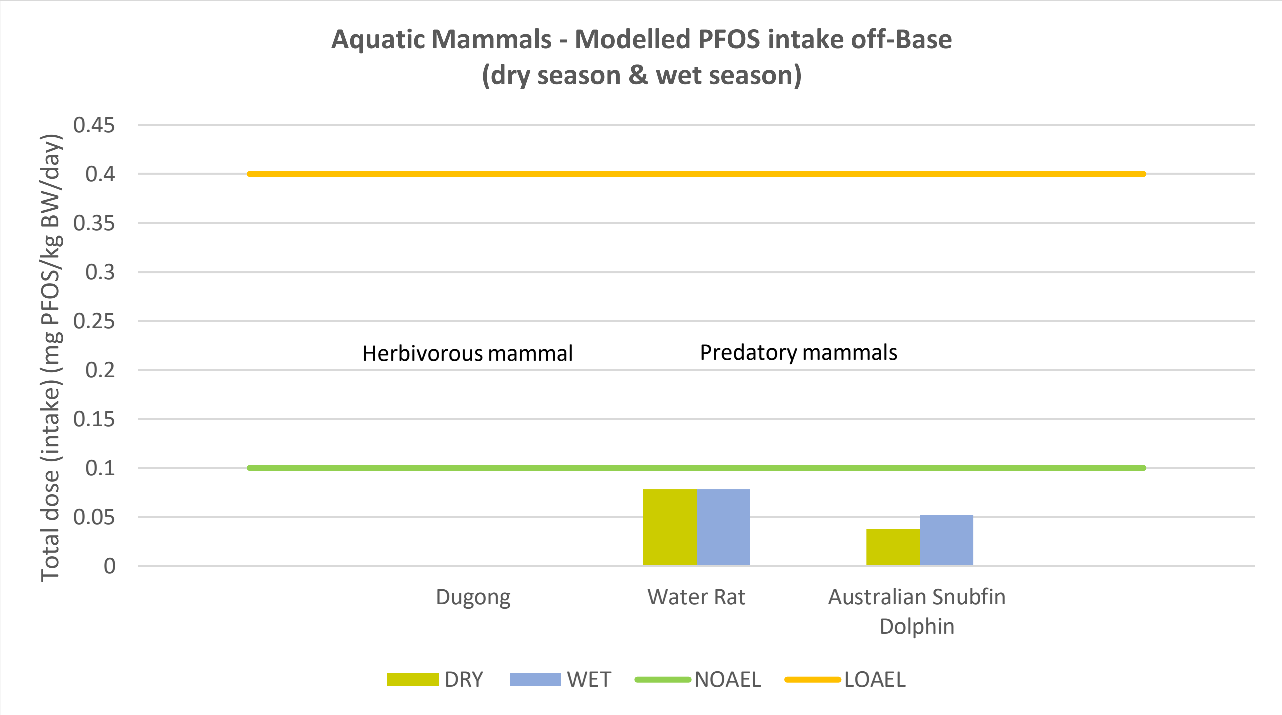


Figure 11.8 Modelled PFOS intake for aquatic mammals off-Base (dry and wet season results)

Figures 11.7 and 11.8 above indicate that for:

- Predatory mammals (on-Base), the total intake dose modelled from dietary exposure was above the NOAEL TRV during wet season conditions but not dry seasons; but was below the LOAEL TRV.
- Herbivorous mammals and predatory mammals (off-Base), the total intake dose modelled from dietary exposure was below both the NOAEL and LOAEL TRVs, for dry and wet seasons.

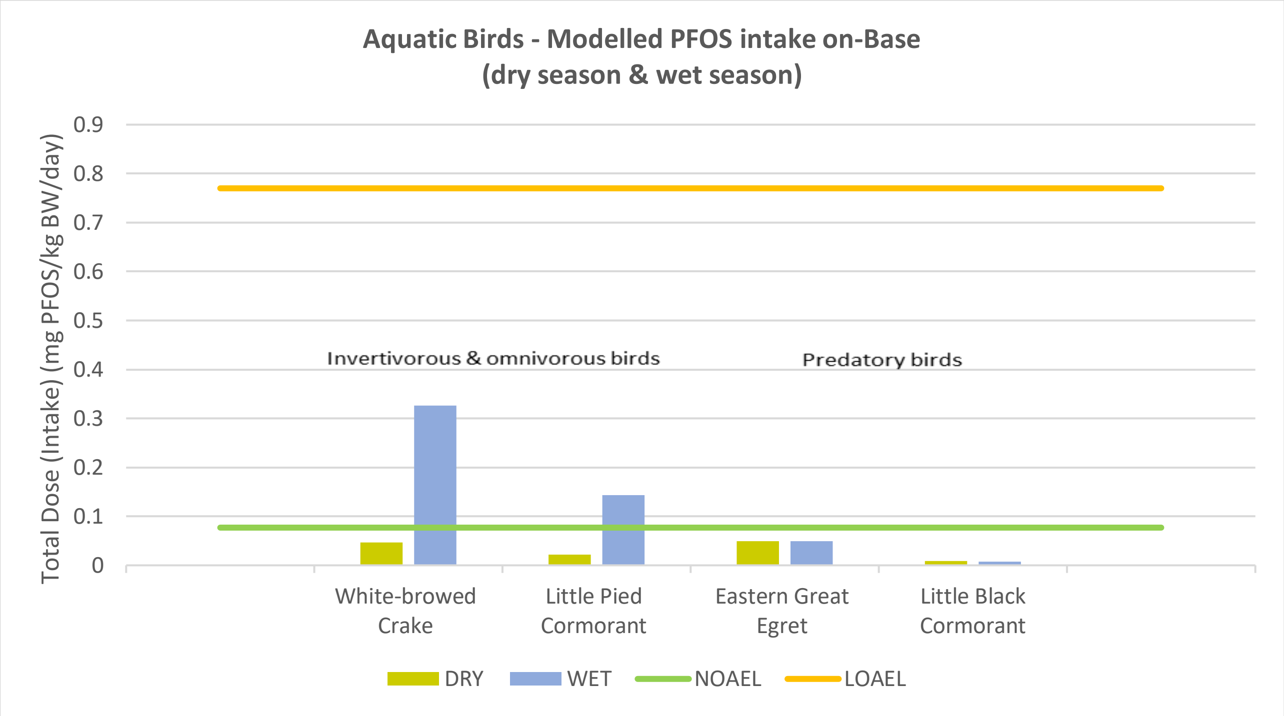


Figure 11.9 Modelled PFOS intake for aquatic birds on-Base (dry and wet season results)

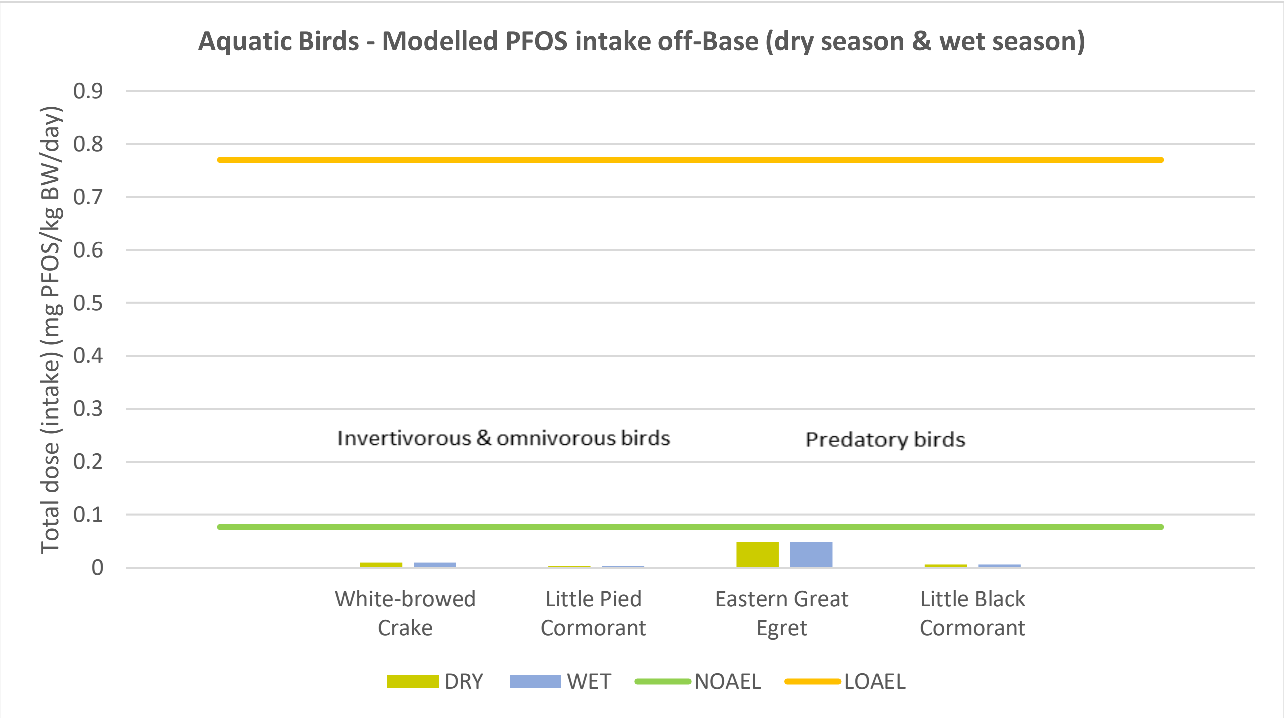


Figure 11.10 Modelled PFOS intake for aquatic birds off-Base (dry and wet season results)

Figures 11.9 and 11.10 above indicate that for:

- Invertivorous and omnivorous birds (on-Base), the total intake dose modelled from dietary exposure is below the NOAEL TRV for dry season conditions. However, for wet season conditions, the modelled intake is above the NOAEL TRV (but below the LOAEL TRV).
- Predatory birds (on-Base), the total intake dose modelled from dietary exposure is below both the NOAEL and LOAEL TRVs for dry and wet seasons.
- Invertivorous and omnivorous birds (off-Base), the total intake dose modelled from dietary exposure is below both the NOAEL and LOAEL TRVs for dry and wet seasons.
- Predatory birds (off-Base), the total intake dose modelled from dietary exposure is below both the NOAEL and LOAEL TRVs for dry and wet seasons.

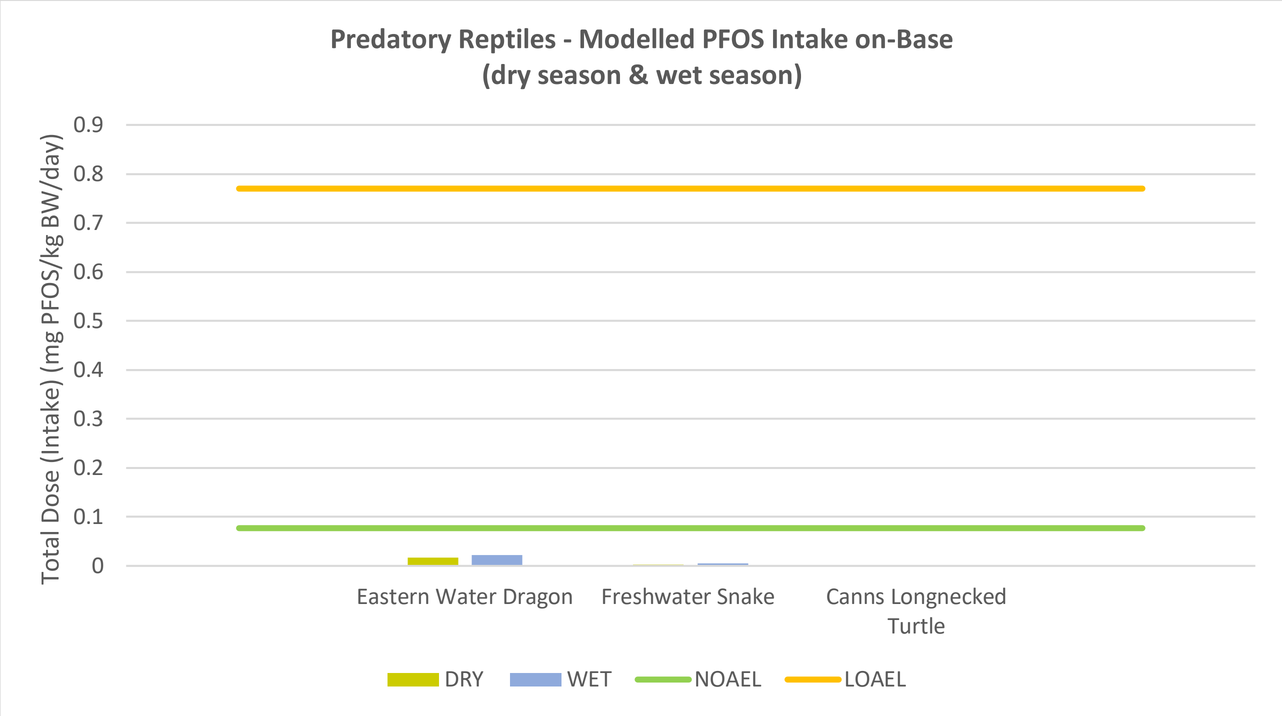


Figure 11.11 Modelled PFOS intake for aquatic reptiles on-Base (dry and wet season results)

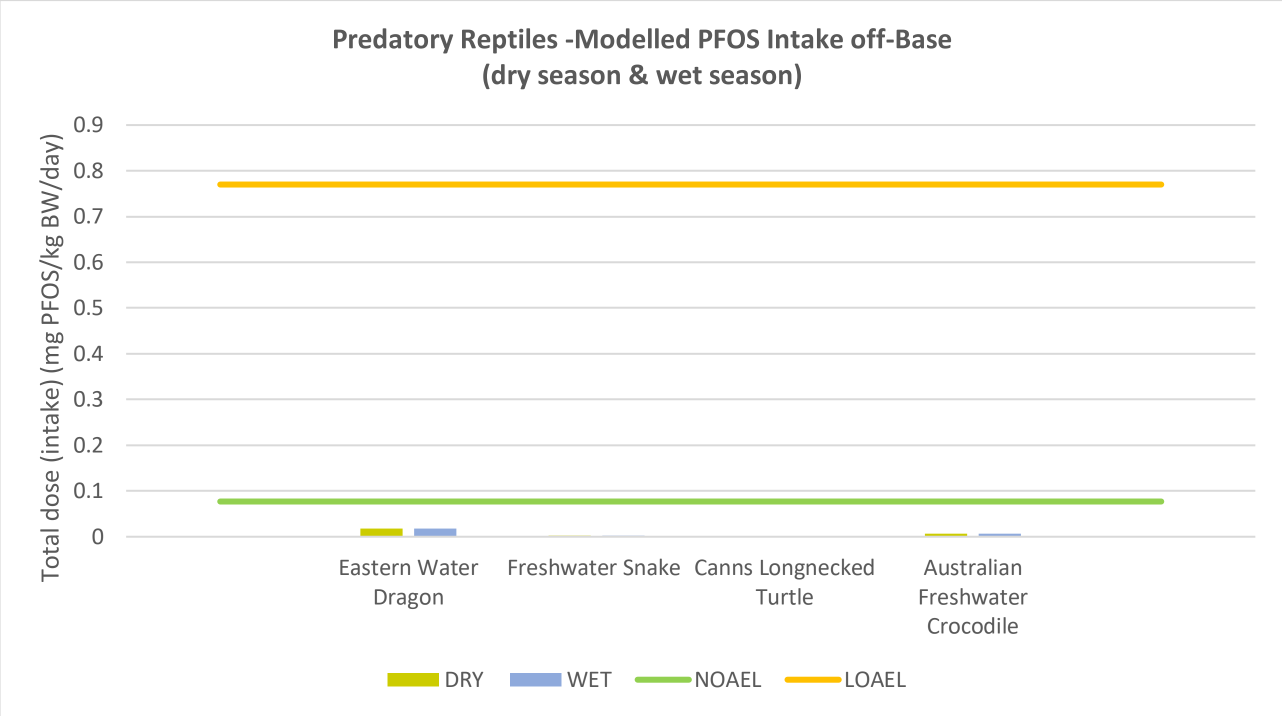


Figure 11.12 Modelled PFOS intake for aquatic reptiles off-Base (dry and wet season results)

Figures 11.11 and 11.12 above indicate that for:

— Predatory reptiles (on and off-Base), the total intake dose modelled from dietary exposure is below the NOAEL and LOAEL TRVs for dry and wet seasons.

In summary, based on total PFOS intake estimates from dietary exposure, the following on-Base aquatic trophic levels exceed the NOAEL indicating there may be a potential risk for the bioaccumulation of PFOS:

— Predatory mammals (wet season only) and invertivorous and omnivorous birds (wet season only).

No aquatic trophic levels exceed the LOAEL.

A summary of the risk evaluation for aquatic species is provided in Table 11.8 below. The potential risk to receptors has been assessed via comparison of the total intake dose to the adopted NOAEL and LOAEL TRVs, i.e. risk is deemed low and acceptable if the total intake dose is below the NOAEL (and LOAEL) or a potential for elevated exposure risk if the total intake dose is greater than the NOAEL (and LOAEL).

Based on the risk evaluation for aquatic species outlined above, invertivorous and omnivorous birds and predatory mammals were the only trophic level which displayed a change in their potential risk based on their location, i.e. total intake dose on-Base compared to off-Base. Where differences for total intake doses were noted between seasons, it was higher in the wet season compared to dry season, and with the exception of predatory birds, the total intake dose was higher on-Base compared to off-Base for at least one of the seasons (noting that herbivorous mammals were not assessed on-Base). In these cases, the differences were largely driven by the increased EPC on-Base compared to off-Base for sediment and surface water, and the higher EPC for sediment on-Base for the wet season. This resulted in an increased modelled intake dose for these species who are assumed to ingest sediment and water as a portion of their total dietary intake.

As noted in Section 10.1, in the absence of specific TRVs for reptiles, risks to reptilian receptors have been evaluated based on a comparison with avian TRVs. The measured PFOS concentrations identified within reptiles within the Town Common, Rowes Bay and Louisa Creek (average PFOS concentration of 1,444 µg/kg and a maximum concentration of 14,900 µg/kg) suggest that bioaccumulation of PFOS may be occurring within reptilian species (namely the freshwater snake and the Canns Longnecked turtle, evaluated as part of the aquatic and terrestrial/semi-terrestrial food web models respectively). However, no single risk driving pathway was identified for these receptors. Whilst no elevated exposure risk was identified, further assessment including the derivation of a reptile specific TRV would enable refinement of the exposure assumptions adopted for this ERA.

Table 11.8 Aquatic species – risk evaluation

RECEPTOR	TOTAL INTAKE DOSE (mg PFOS/kg BW/DAY) [1]		NOAEL TRV (mg/kg BW/DAY)	LOAEL TRV (mg/kg BW/DAY)	RISK EVALUATION
	on-base	off-base			
Herbivorous mammals	Not assessed for on-Base	0.0003 (dry season) 0.0004 (wet season)	0.1	0.4	Low and acceptable for off-Base
Predatory mammals	0.09 (dry season) 0.12 (wet season)	0.08 (dry season) 0.08 (wet season)			Potential for elevated exposure risk - on-Base Low and acceptable for off-Base
Invertivorous & Omnivorous birds	0.05 (dry season) 0.33 (wet season)	0.010 (dry season) 0.010 (wet season)	0.077	0.77	Potential for elevated exposure risk - on-Base Low and acceptable for off-Base
Predatory birds	0.05 (dry season) 0.05 (wet season)	0.05 (dry season) 0.05 (wet season)			Low and acceptable for on-Base Low and acceptable for off-Base
Predatory reptiles	0.017 (dry season) 0.022 (wet season)	0.017 (dry season) 0.017 (wet season)			Low and acceptable for on-Base Low and acceptable for off-Base

Notes:

(1) Total intake doses are the highest modelled intakes for a receptor within each trophic level (where more than one receptor was evaluated for a trophic level). Refer Appendix G for individual species modelled intakes.

12 UNCERTAINTY ASSESSMENT

The uncertainty assessment identifies the sources of uncertainty within the main components of the ERA and their potential impact on the risk estimates and conclusions of the ERA.

Of note, one of the primary uncertainty factors when undertaking food web modelling is the absence of species specific food and water ingestion rates for some Australian species. In the absence of Australian data, it is unclear whether the adopted assumptions would result in an under or over estimation of risks.

Table 12.1 below summarises those modelling parameters which provide a source of uncertainty in the ERA and evaluates the impact this may have on the outcome of the ERA.

Table 12.1 Uncertainty analysis

MODELLING PARAMETER	RANGE OF VALUES	VALUE ADOPTED	OUTCOME IN THE ERA
Exposure point concentration	Refer to Table 9.5 (terrestrial and semi-terrestrial) and Table 9.6 (aquatic)	Dependant on the dataset but was based on: — the 95% UCL — the arithmetic mean of detected concentrations — the detected concentration (if only one concentration detected) — the maximum concentration; or — a substituted concentration if no site-specific data available	— When sufficient data was available for a particular exposure unit, the 95%UCL was adopted as the EPC as this was considered to provide a representative concentration across each exposure unit. — The arithmetic mean was determined from detected concentrations only. Adopting the average concentration as the EPC may result in an overestimation of the risks to receptors. — Only one detectable concentration was reported from plant data and this was adopted as the EPC. This may result in an overestimation of the risks to receptors as it assumes this concentration is representative across the exposure unit, however all remaining concentrations were reported below this. — The maximum detected concentration was adopted when insufficient data above the detection limit was available. This may result in an overestimation of the risks to receptors. — In the absence of site-specific data, the adopted EPC was based on an exposure concentration from another Defence PFAS investigation site. The data was based on direct measurements of biota and considered appropriate in the absence of site-specific information.
Body weight	Refer to Table 9.7 (terrestrial & semi-terrestrial), Table 9.8 (aquatic), and Appendix G	The average of the reported weight ranges	The average body weight was adopted to account for a range of body weights. The risk to individuals above or below the average weight may be slightly over- or underestimated.

MODELLING PARAMETER	RANGE OF VALUES	VALUE ADOPTED	OUTCOME IN THE ERA
Home range	15,570 hectares		The home range value adopted was based on twice the size of the Investigation Area to account for migratory species which move to areas outside the Investigation Area. Given the extensive migration of some bird species (identified in the Investigation Area), the adopted home range value is considered very conservative and therefore likely results in an overestimation of risks to migratory receptors.
Food and water ingestion rates	Refer to Table 9.7 (terrestrial & semi-terrestrial), Table 9.8 (aquatic), and Appendix G		Food ingestion rates for selected ROC were adopted from Nagy (2001) where available. For ROCs not available, rates were estimated based on equations published in Nagy (2001) derived through extrapolation from measured field metabolic rates and information on dietary energy content. The empirical coefficients for birds, mammals and reptiles presented in Nagy (2001) were also utilised. The water ingestion rate was calculated from the equation adopted in US EPA (1999) for birds and mammals (based on body weight). A default value was adopted for reptiles. The adoption of these values from whole datasets of species utilise average body weights, are gender neutral and do not account for different habitats, activity, etc. There may be an over- or underestimation of food/water ingestion rates and therefore an over- or underestimation of potential risk to receptors.
Diet composition	Refer to Table 9.7 (terrestrial & semi-terrestrial), Table 9.8 (aquatic), and Appendix G		Particular diet composition of receptors was estimated based on professional judgement from available information. Given the lack of specific data relating to this parameter, this was considered an acceptable approach. This may result in over- or underestimation of the potential risk to receptors with a more complex diet composition.

MODELLING PARAMETER	RANGE OF VALUES	VALUE ADOPTED	OUTCOME IN THE ERA
Assumed concentrations in food sources	Appendix G	Conservative EPCs have been adopted (Appendix G)	The modelling of a receptor's exposure from ingestion of dietary items assumes all items contain PFAS, however it is more likely that not all dietary components would contain PFAS as they are sourced from different areas and seasonal variation may also occur. Average concentrations have been utilised in the adopted EPCs for aquatic invertebrates and terrestrial mammals which may result in an overestimation of the risks to receptors who consume these two food groups.
Area contaminated	7785 hectares		The whole Investigation Area has been assumed to be contaminated at the concentration adopted for the EPC. This does not account for the range of reported concentrations for various media, as well as seasonal variability which appears to be occurring to some degree. This therefore likely results in an overestimation of risks to ecological receptors.
Proportion of available suitable habitat in contaminated area	0 to 100%	100% for migratory species	It has been assumed for modelling purposes that the proportion of available suitable habitat within the Investigation Area is 100%. This is considered to be conservative, as it is more likely the migratory species may move outside of the Investigation Area reducing their potential exposure to PFAS. This may result in an overestimation of the risk to these species, but is considered appropriate in the absence of specific data.

MODELLING PARAMETER	RANGE OF VALUES	VALUE ADOPTED	OUTCOME IN THE ERA
Toxicity reference values	PFOS (birds/reptiles): 0.077 mg/kg BW/day (NOAEL) and 0.77 mg/kg BW/day (LOAEL) PFOS (mammals): 0.1 mg/kg BW/day (NOAEL) and 0.4 mg/kg BW/day (LOAEL)		TRVs were based on the results of a literature search and review of other available sources. Toxicological information on PFAS is continuing to expand and the range of PFAS compounds being studied is increasing. The TRVs adopted were based on the literature available at the time and considered PFOS and PFOA which much of the available information and research is focussed on. As more research is conducted, more or less conservative TRVs may become available, however the adopted TRVs are considered suitable based on the information currently available. Of note, an uncertainty factor of 10 was applied to extrapolate from the LOAEL to the NOAEL TRV for birds/reptiles. No further uncertainty factors were applied for this assessment as the risk characterisation step for higher order species, has assessed the modelled intake doses (from dietary exposure) against the relevant TRVs, to assess if a potential elevated exposure risk may exist for a species.

13 CONCLUSIONS

WSP has undertaken an ecological risk assessment (ERA) to quantitatively assess the risk to the environment resulting from exposure to the historical use of Aqueous Film Forming Foams (AFFF) containing PFAS at the Royal Australian Air Force (RAAF) Base Townsville. The ERA has incorporated both on-Base and off-Base areas and is defined as the Investigation Area shown on Figure 1, Appendix A.

DSI works undertaken by WSP (2018a and 2018b) have identified concentrations of PFAS compounds in soil, groundwater, surface water, sediments and aquatic biota. To further support the completion of the ERA, WSP (2018d) also completed semi-terrestrial biota sampling within off-Base areas. This data has been used to assist in the characterisation of potential ecological risks in both on-Base and off-Base areas. The data to date is also being utilised as input to the PFAS Management Area Plan (PMAP) currently under development. The PMAP seeks to provide management plans to mitigate the potential impact to human health and the environment from identified PFAS in the Investigation Area and to mitigate the potential migration of PFAS off-Base.

On the basis of the available data including the uncertainties identified in this ERA, the following conclusions are provided below and should be considered in consultation with the relevant stakeholders.

13.1 LOWER ORDER SPECIES – ON-BASE AND OFF-BASE

13.1.1 TERRESTRIAL AND SEMI-TERRESTRIAL RECEPTORS

The findings of the ERA have identified that there is a potential for adverse effects to occur to terrestrial species, based on a comparison of the reported soil concentrations of PFOS on-Base and off-Base to adopted screening benchmarks.

13.1.2 AQUATIC RECEPTORS

Aquatic environments on-Base are only considered relevant during the wet season when the wetland area (as depicted on Figure 1, Appendix A) is likely to be in use by ecological receptors (i.e. aquatic birds and semi-terrestrial species). The findings of the ERA have identified that there is a potential for adverse effects to occur to aquatic species, based on a comparison of the reported surface water and sediment concentrations on-Base to adopted screening benchmarks.

For off-Base aquatic environments, the findings of the ERA have identified that there is a potential for adverse effects to occur to aquatic species, based on a comparison of the reported surface water and sediment concentrations off-Base to adopted screening benchmarks.

The evaluation of adverse effects to aquatic species, based on biota tissue samples for fish, crustaceans and molluscs collected off-Base, identified a possible risk for toxicity to mammals and birds who consume aquatic biota including fish and crustaceans. No toxicity risks were identified for aquatic plants based on a comparison against adopted screening benchmarks.

An evaluation of bioaccumulation was also undertaken for aquatic receptors where available co-located samples (off-Base) were completed for surface, sediment and biota. The co-located results were used to calculate a representative BAF. Whilst based on limited data, the calculated BAFs indicate that some bioaccumulation is potentially occurring within benthic invertebrates, which does not appear to be dependent on sample location or distance from source areas, based on the high variability observed in the calculated BAFs. It is considered that a range of factors are likely to be influencing the nature and extent of bioaccumulation that occurs within aquatic organisms.

13.2 HIGHER ORDER SPECIES – ON-BASE AND OFF-BASE

13.2.1 TERRESTRIAL AND SEMI-TERRESTRIAL RECEPTORS

The evaluation of adverse effects to semi-terrestrial species, based on biota tissue samples collected off-Base, identified a possible toxicity risk for mammalian and/or avian consumers of amphibian and reptile biota within the Investigation Area. This includes secondary and tertiary consumers of biota when comparing biota tissue results against the adopted screening benchmarks for mammalian and/or avian consumers of biota. Further evaluation of potential risks to higher order species was conducted via quantitative food web modelling for representative terrestrial/semi-terrestrial receptors and is discussed further below.

Potential risks to higher order species was conducted via a combination of (i) quantitative food web modelling to estimate a total dose intake from dietary exposure; and (ii) undertaking a comparison of the modelled intakes against the relevant TRVs for birds/reptiles and mammals. The results of the risk evaluation identified that a potential elevated exposure risk (from dietary exposure) may exist to:

- herbivorous mammals
- invertivorous and omnivorous mammals
- herbivorous birds
- invertivorous and omnivorous birds; and
- predatory birds.

13.2.2 AQUATIC RECEPTORS

For aquatic receptors, the risk evaluation identified that a potential elevated exposure risk (from dietary exposure) may exist to:

- predatory mammals; and
- invertivorous and omnivorous birds.

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