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Department of Defence

RAAF Base Darwin

Human Health Risk Assessment for PFAS
Executive Summary

19 June 2018

When you
think with a
global mind
problems
get smaller

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RAAF Base Darwin

Prepared for
Department of Defence

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19 June 2018

754-MELEN199421_R07ES

Quality information

Revision history

Revision	Description	Date	Author	Reviewer
V1	Draft	21 May 2018	Nick Woodford	Sarah Richards
V2	Revised Draft	15 June 2018	Nick Woodford	Sarah Richards
V3	Final	18 June 2018	Nick Woodford	Sarah Richards

Distribution

Report Status	No. of copies	Format	Distributed to	Date
Draft	1	Word and PDF	Department of Defence	18 May 2018
Revised Draft V2	1	Word and PDF	Department of Defence	15 June 2018
Final	1	PDF	Department of Defence	19 June 2018

EXECUTIVE SUMMARY

Introduction

The Department of Defence (Defence) engaged Coffey Environments Australia Pty Ltd (Coffey) to conduct a Human Health Risk Assessment (HHRA) associated with the detection of per- and polyfluoroalkyl substance (PFAS) in the environment from use of legacy aqueous film forming foam (AFFF) at Royal Australian Air Force (RAAF) Base Darwin (the Base).

RAAF Base Darwin and the Darwin International Airport (DIA) is an operational joint civil-military airfield. AFFF containing PFAS was used on the estate from approximately 1970 until 2005. The historical use and storage of AFFF for firefighting activities on-Base included active suppression of fires, training for emergency use, testing of related equipment, and fixed fire suppression systems in an aircraft hangar and bulk fuel storage facilities.

Defence recognised that the former use of these chemicals may have resulted in releases to the environment and exposure to human receptors. Defence are seeking to better understand the nature and extent of PFAS impacts on the Base (and within the greater Investigation Area) via the completion of a comprehensive investigation of PFAS site conditions, which included the completion of this HHRA. The comprehensive investigation also included the preparation of a detailed site investigation (DSI) and an ecological risk assessment (ERA).

PFAS compounds

Per- and poly-fluorinated alkyl substances are a class of manufactured chemicals that have been used since the 1950s to make products that resist heat, stains, grease and water. Due to their heat resistant properties, and ability to form aqueous film forming foams, they have been used extensively in fire-fighting foam applications, both worldwide and within Australia, from the 1970s.

Research has been conducted into the behaviour of these substances in the environment, and they are understood to be highly persistent, be readily leachable from soils, and bio-accumulate up the food-chain. The potential health and ecological effects of these substances are not well defined; however, given their environmental persistence, the Environmental Health Standing Committee (enHealth) has issued a precautionary warning to limit exposure to humans from these compounds.

The fully fluorinated (per-) compounds do not degrade and will remain in the environment for many decades. These compounds are both water soluble and mobile, and will tend to migrate with the movement of water. Different compounds in the group adsorb at different rates to organic carbon in soil. Long chain compounds (six or more carbons) also bioaccumulate in animals. Due to the mobility, PFAS compounds can be present in very large plumes associated with groundwater migration and surface waters.

The main AFFF product used historically by Defence until the 2000s was 3M Lightwater™ for which the active ingredients include per-fluorooctane sulfonate (PFOS), per-fluorohexane sulfonate (PFHxS) and to a lesser extent perfluorooctanoic acid (PFOA).

Objectives, scope and approach

The objectives of the HHRA were to:

- Understand the potential human exposure risks associated with contamination from the historical use of legacy AFFF containing PFAS compounds, to on-Base and off-Base receptors within the Investigation Area; and
- Identify the main exposure pathways to guide risk management.

The scope of the HHRA involved:

- Review and incorporation of the results from additional monitoring conducted subsequent to the completion of the DSI report in order to refine the Tier 1 screening level risk assessment;
- Refinement of the conceptual site model (CSM) described in the DSI, based on the additional monitoring;
- Estimation of PFAS intakes for receptor groups within the Investigation Area;
- Comparison of the estimated PFAS intake for each receptor group to tolerable daily intakes[1] (TDI);
- Characterisation of the potential risk to human health for receptor populations in the Investigation Area who have been or may be exposed to the PFAS impacts in various environmental media; and
- Determine which exposure pathways require further evaluation or management to reduce or minimise potential exposures.

The Investigation Area was defined during the DSI to reflect the extent of potential PFAS impact and to focus the investigation, based on suspected release sites and contaminant migration pathways. The Investigation Area is shown in Figure A.

Figure A – Base Location and Investigation Area

The health risk assessment approach was consistent with relevant Australian guidance and protocols endorsed by Australian regulators. The HHRA framework is specified in the '*National Environment Protection (Assessment of Site Contamination) Amendment Measure 2013*' (NEPC, 2013), referred to

[1] a tolerable daily intake that is expected to be without appreciable health risk, based on toxicological studies and incorporating a range of uncertainty (safety) factors

herein as the NEPM and the '*Guidelines for Assessing Human Health Risks from Environmental Hazards*' (enHealth, 2012a). Consistent with the guidance, the risk assessment process for the HHRA comprises issue identification and data evaluation using Tier 1 screening criteria (such as the NEPM (2013) Health Investigation Levels), where further assessment was warranted a toxicity assessment, exposure assessment and risk characterisation has been completed.

Conceptual Site Model

In order to identify which receptor groups may potentially be exposed to PFAS released to the environment as a result of the use of AFFF containing PFAS, a conceptual site model was formulated. Sources of on-Base PFAS contaminants were identified including areas where AFFF was stored, handled and used. The fate and transport of PFAS was then assessed based on the Investigation Area conditions (topography, geology, hydrogeology, climate, surface water and drainage). Human receptor populations were then identified based on the extent of impact, and the potential exposure routes were assessed. The CSM is summarised below.

Sources

Sixteen potential PFAS source areas were identified on-Base, and one off-Base, which was previously operated by Defence. The identification of the source areas was based on the review of existing reports or anecdotal evidence suggesting legacy AFFF use. Following the DSI investigation, the following areas are considered to be the major PFAS source areas based on the observed concentrations in soils and groundwater (as presented on Figure B):

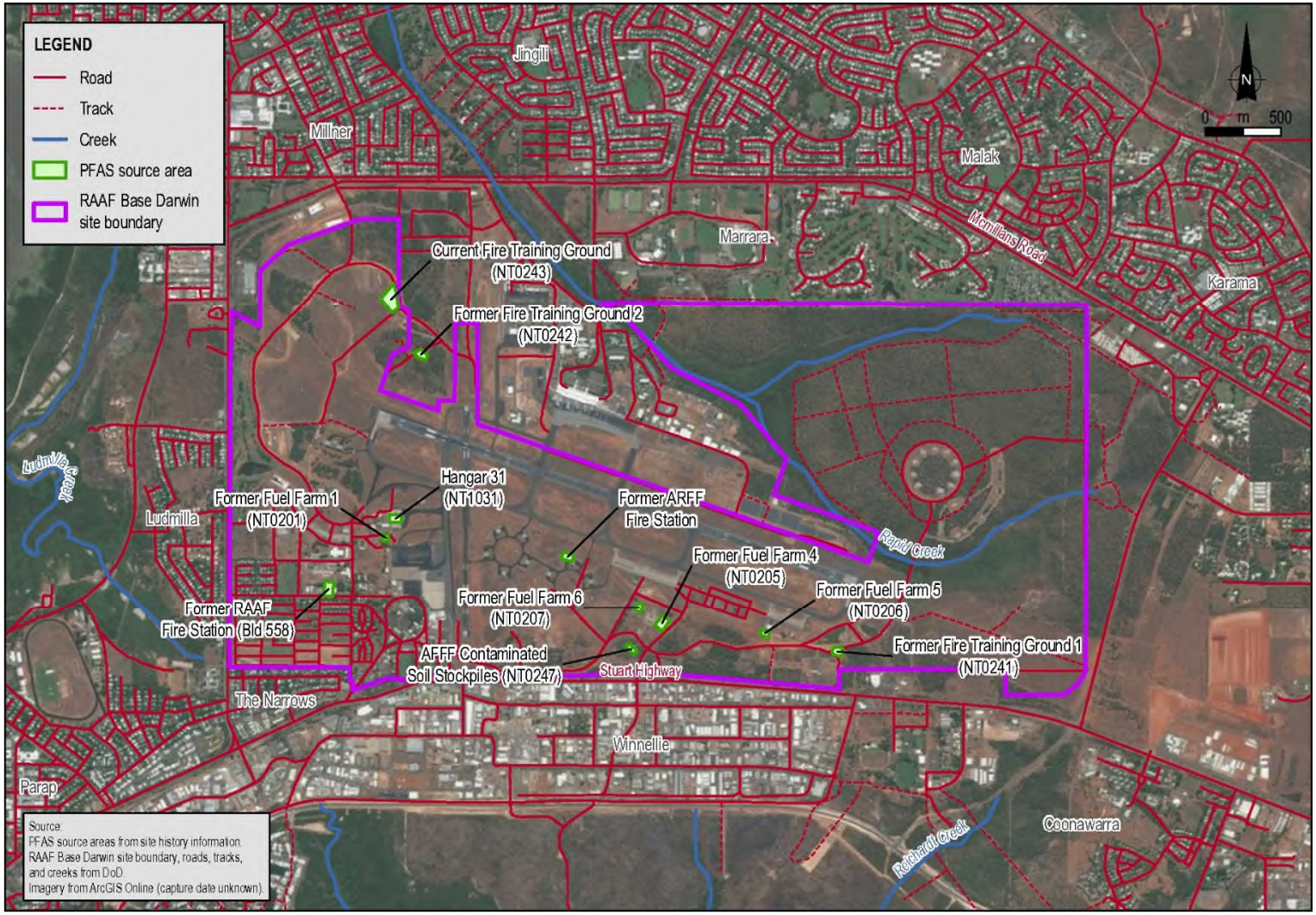
- Former Fire Training Ground 1 (NT0241);
- Former Fuel Farm 5 (NT0206), 4 (NT0205) and 6 (NT0207);
- Stockpiled AFFF Contaminated Soil (NT0247);
- Former Aviation Rescue and Fire Fighting (ARFF) Fire Station;
- Hangar 31 (NT1031) and Former Fuel Farm 1 (NT0201);
- Former RAAF Fire Station;
- Former Fire Training Ground 2 (NT02542) (off-Base); and
- Current Fire Training Ground.

Transport Pathways

Potential pathways for the migration of PFAS associated with application and use of AFFF at the source sites include the following:

- Leaching of PFAS from impacted soils into groundwater;
- Surface water runoff of PFAS from surface soils to drains, depressions, open pits and surrounding creeks;
- Migration of PFAS in surface water (drains and surrounding creeks) to down-stream areas;
- Infiltration of PFAS in surface water to soil and groundwater;
- Lateral migration of PFAS in groundwater with the flow of the aquifer;
- Potential extraction of groundwater for irrigation use;
- Discharge of groundwater into surface waters and associated sediments. This includes discharge of groundwater into unlined and lined stormwater drains;
- Uptake of PFAS from sediment, groundwater and surface water by plants and animals; and
- Release of PFAS to the environment from the decomposition of PFAS contaminated biota.

Figure B – Locations of Identified PFAS Source Areas



Receptors

The human receptors of potential PFAS contamination were identified as:

- RAAF Base Darwin personnel;
- On-Base maintenance workers conducting shallow (<1m) sub-surface works or working on waste water infrastructure;
- On-Base construction workers conducting deep excavation works;
- On-Base residents of RAAF Base Darwin;
- Off-Base commercial and industrial workers in areas surrounding the Base;
- Off-Base maintenance workers conducting shallow (<1m) sub-surface works in areas surrounding the Base and affected catchments;
- Off-Base construction workers conducting deep excavation works in areas surrounding the Base and affected catchments;
- Off-Base residents primarily those surrounding the Base and in affected catchments;
- Recreational users, undertaking activities such as swimming and fishing, within Rapid Creek, Ludmilla Creek, Sadgroves Creek and Reichardt Creek; and
- Potential users of extracted groundwater down-gradient of source areas.

It is noted that the extraction of groundwater or surface water for potable use is considered highly unlikely; however, there is no mechanism that provides control over the use of extracted water.

Exposure routes

The selection of potential exposure routes is based on toxicity studies and the physicochemical properties of PFAS compounds. Routes of exposure whereby a contaminant may enter the body are via inhalation, ingestion and dermal contact.

Direct ingestion (i.e. ingestion of impacted soil or water) and indirect ingestion, via bioaccumulation of PFAS in biota and animal products, have been demonstrated in literature and previous studies to be the most significant exposure routes and are, therefore, considered to be the dominant exposure pathways for evaluation.

PFOS, PFHxS and PFOA compounds are not readily adsorbed into the systemic system when exposed via dermal contact. Whilst the contribution of dermal contact pathways to the overall risks to human health is considered to be small, dermal contact is likely to be a complete exposure pathway in many instances and was therefore included in the risk assessment.

As PFOS, PFHxS and PFOA are not volatile, exposures via the inhalation pathway is likely to be limited. The assessment of inhalation exposures has been limited to inhalation of soil derived dust.

Nature and extent of impact

Soil

The extent of contaminated soil from the PFAS source areas identified during the DSI was limited to on-Base and on the perimeter of the DIA land around Former Fire Training Ground 2 (NT0242) and the Current Fire Training Ground (NT0243). It is noted that the DSI sampling did not target the Current Airservices Fire Station or other areas on DIA land.

The maximum concentrations of PFAS compounds were reported at the Former Fire Training Ground 1 (NT0241) with PFOS + PFHxS concentrations up to 70.6 mg/kg. Lateral delineation to below the

adopted criteria was achieved in all directions in each of the source areas. The soil sampling program did not identify PFOA to be above the adopted health criteria in any of the samples analysed.

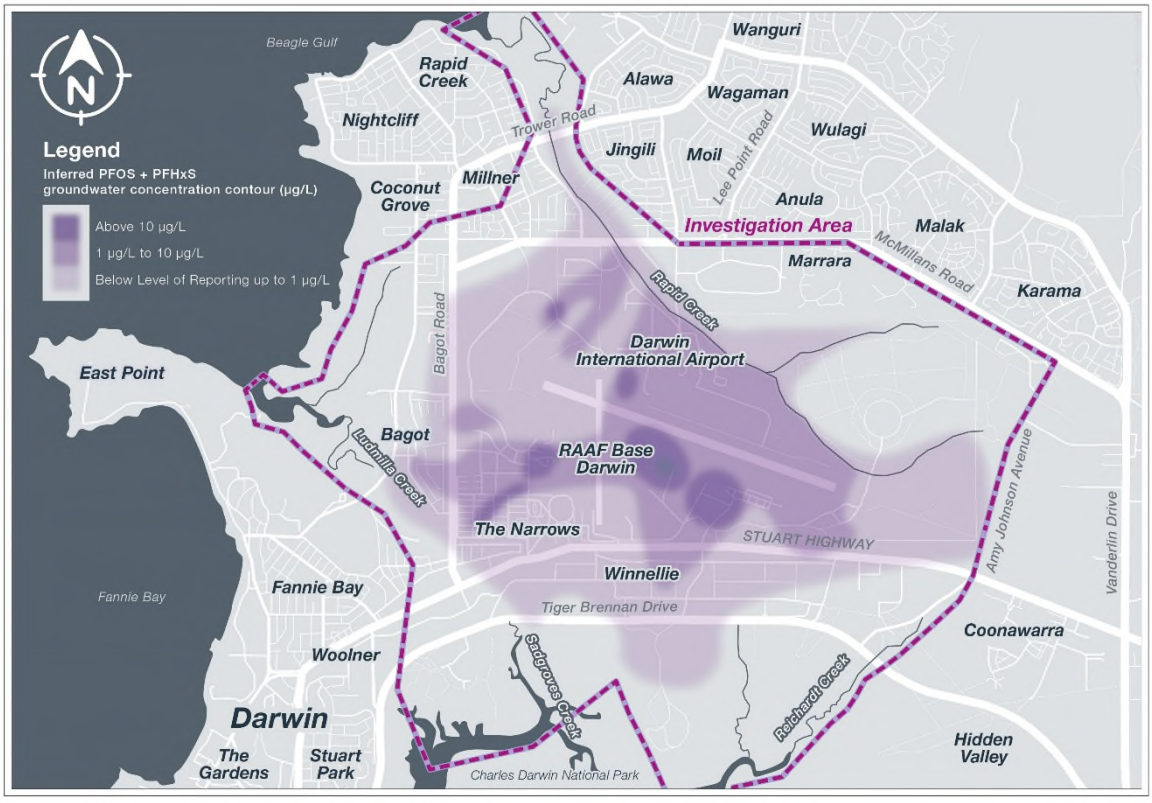
Groundwater

Both PFOS + PFHxS and PFOA have been reported above the adopted human health screening criteria in groundwater beneath the Investigation Area. PFOS + PFHxS was reported with concentrations up to 820 µg/L and PFOA was the reported with concentrations up to 10 µg/L. Elevated concentrations of PFAS in groundwater were associated with all of the key PFAS source areas listed above, with the exception of the AFFF Contaminated Soil Stockpiles (NT0247) area.

The groundwater flow direction appears to follow surface topography with the highest elevation located to the south of the runway near the Former ARFF Fire Station. In the north of the Base and on DIA land, groundwater flows to the north-west following the flow direction of Rapid Creek. In the west of the Base groundwater flows west and southwest into made drains and Ludmilla Creek. Along the southern boundary, groundwater flows to the south to Sadgroves Creek and Reichardt Creek.

Generalised PFOS + PFHxS contours are presented in Figure C below.

Figure C: PFOS + PFHxS groundwater concentrations contours



Concentrations of PFAS were observed to decrease along the groundwater flow paths with distance from the source areas. With the exception of Rapid Creek and two narrow pathways towards Ludmilla Creek and Sadgroves Creek, groundwater concentrations of PFAS were reported to have decreased to concentrations below the laboratory reporting limit prior to discharging to surface water.

Surface water and sediments

The Base is drained by large open unlined drains, municipal drains and underground piping. The surface water generally drains into Rapid Creek on the north and east (via Marrara Swamp) sides of the Base, Sadgroves Creek on the south, and Ludmilla Creek on the west. A small central portion of the Base on the southern boundary discharges to Reichardt Creek.

PFOS + PFHxS have been reported above the adopted human health screening criteria for direct contact in the drainage network and in Rapid Creek and Ludmilla Creek, and to a lesser degree Sadgroves Creek and Reichardt Creeks. Inferred surface water PFOS + PFHxS concentrations are presented in Figure D and have been related to drinking water and recreational use guidance values to provide context.

Figure D: Inferred surface water PFOS + PFHxS concentrations

Concentrations of PFOS + PFHxS in the section of Rapid Creek adjacent to DIA to Trower Road, have been consistently reported above the recreational health based guidance values (0.7 μg/L) with a maximum concentrations of 2.48 μg/L. Concentrations were lower upstream of where stormwater and groundwater discharge from the Base enters Rapid Creek, and downstream beyond Trower Road, where tidal flushing occurs.

PFOS + PFHxS concentrations in Ludmilla Creek were highest where stormwater drains from the Base discharge to the upper section of Ludmilla Creek. Concentrations in the discharging drain were consistently above recreational guidance values, up to 10.2 μg/L. Concentrations in the section of Ludmilla Creek west of Dick Ward Drive were lower, but were reported up to 0.13 μg/L in the wet season.

Concentrations were not consistently detected above the laboratory reporting limit in Sadgroves Creek and Reichardt Creek and no exceedances of recreational health based values were reported. Maximum PFOS + PFHxS concentrations reported were 0.39 μg/L and 0.1 μg/L in Sadgroves and Reichardt creeks respectively.

PFOA was reported to be below the adopted human health screening criteria in all samples collected.

With the exception of one sample collected from the Current Fire Training Ground (NT0243) waste water infrastructure, all on-Base samples reported concentrations of PFOS + PFHxS below the health screening levels adopted for the commercial or maintenance and construction settings.

Terrestrial biota

A range of terrestrial biota was sampled or considered in the risk assessment.

Fruit and vegetable samples were collected from the Jingili Council Orchard, Jingili Community Gardens and Lakeside Community Gardens. All PFAS compounds were reported to be below the limit of reporting (LOR) and adopted criteria in all samples collected from the community gardens.

Samples were also collected from native edible plants adjacent to the surface water bodies as part of a broader flora assessment. PFOS + PFHxS was reported above the LOR but below the adopted criteria in plants potentially used for edible leafy greens and herbs. Concentrations were below the LOR in edible fruits. PFOA was reported to be below the LOR and adopted criteria in all of the native edible samples collected.

Sampling and analysis of native animals was not extensive, as human consumption of animals that are likely to be exposed to PFAS from the Base was not identified as a significant pathway. However, some testing was conducted for targeted game or as part of the ecological risk assessment. The concentrations of PFOS + PFHxS and PFOA in native mammal and bird samples did not exceed the adopted health screening criteria. Elevated concentrations of PFAS compounds were identified in two snake samples recovered from the Rapid Creek and Ludmilla Creek areas. Snake has not been identified as a common food in the area.

There were insufficient home-grown poultry eggs identified for sampling from within the Investigation Area to provide reliable field data. As such, PFAS concentrations in poultry eggs were estimated using soil and water concentrations in each of the residential areas surrounding the Base. Based on the estimation of PFAS concentrations in poultry eggs, concentrations of PFOS + PFHxS may exceed the adopted screening criteria in the event that residents of Bagot use groundwater to water poultry.

Aquatic biota

Aquatic biota species were sampled in Rapid Creek (freshwater and estuarine areas), Ludmilla Creek, Darwin Harbour, Sadgroves Creek and Reichardt Creek. Sampling included species of fish, crustaceans and molluscs.

PFOS + PFHxS was reported above the adopted fish (flesh) health screening criteria in each area. Concentrations of PFOS + PFHxS in the flesh and whole bodies of fish exceeded the adopted health based screening levels in most samples collected from Rapid Creek and Ludmilla Creek, and were highest in the upstream sections away from tidal flushing. A maximum concentration of PFOS + PFHxS of 1,612 μg/kg was reported in a fish caught in the freshwater portion of Rapid Creek. Only marginal exceedances were reported in two of the many fish caught in Darwin Harbour, Sadgroves Creek and Reichardt Creek.

PFOS + PFHxS was reported above the crustacean health screening criteria in species (Red claw) in the freshwater portion of Rapid Creek and above the adopted mollusc health screening criteria in Ludmilla Creek.

PFOA was reported to be below the screening criteria in all samples tested.

Toxicity assessment

The PFAS toxicity criteria adopted in this assessment were published by the Australian Department of Health. Tolerable daily intake values for chronic exposure (i.e. exposures that occur over months or years) were derived by Food Standards Australia New Zealand for PFOS, PFHxS and PFOA, as these were the compounds most frequently detected and studied in the majority of toxicity studies to date. The main PFAS compounds found in the AFFF relevant for RAAF Base Darwin are PFOS and PFHxS.

Exposure assessment

The exposure pathway evaluation and subsequent Tier 1 screening assessment conducted in the HHRA identified the following exposure scenarios for further quantitative appraisal:

Receptor	Exposure Pathway
Base personnel	Incidental ingestion of surface soil
	Dermal contact with surface soils
	Inhalation of soil derived dusts
	Incidental ingestion of surface water (from surface water drainage networks)
	Dermal contact with surface water (from surface water drainage networks)
On-Base maintenance workers	Incidental ingestion of surface and excavated soils
	Dermal contact with surface and excavated soils
	Inhalation of soil derived dusts
	Incidental ingestion of groundwater
	Dermal contact with groundwater
	Incidental ingestion of surface water (from surface water drainage networks)
	Dermal contact with surface water (from surface water drainage networks)
	Incidental ingestion of effluent water (from surface water effluent tanks)
	Dermal contact with effluent water (from surface water effluent tanks)
On-Base excavation workers	Incidental ingestion of surface and excavated soils
	Dermal contact with surface and excavated soils
	Inhalation of soil derived dusts
	Incidental ingestion of groundwater
	Dermal contact with groundwater
On-Base residents	Inhalation of soil derived dusts
Off-Base commercial / industrial workers	Inhalation of soil derived dusts
Off- Base maintenance workers	Inhalation of soil derived dusts
	Incidental ingestion of groundwater
	Dermal contact with groundwater
	Incidental ingestion of surface water (from surface water drainage networks)
	Dermal contact with surface water (from surface water drainage networks)
Off-Base excavation workers	Inhalation of soil derived dusts
	Incidental ingestion of groundwater
	Dermal contact with groundwater

Receptor	Exposure Pathway
Off-Base residents	Inhalation of soil derived dusts
	Incidental ingestion of extracted bore water by residents using a swimming pool
	Dermal contact with extracted bore water by residents using a swimming pool
	Incidental ingestion of extracted bore water by residents during sprinkler play
	Dermal contact with extracted bore water by residents during sprinkler play
	Ingestion of eggs produced from poultry watered with extracted bore water
Off-Base recreational receptors	Incidental ingestion of surface water by recreational receptors whilst swimming
	Dermal contact with surface water by recreational receptors whilst swimming
Consumers of aquatic biota	Ingestion of fish caught in impacted surface waters by recreational receptors
	Ingestion of crustaceans caught in impacted surface waters by recreational receptors
	Ingestion of molluscs caught in impacted surface waters by recreational receptors

To estimate how much PFAS may enter a human body via dermal contact with, inhalation or ingestion of impacted media (e.g. soil, water or food) the exposure assessment utilised equations with exposure inputs considered to be representative of the particular receptor population. The exposure parameters reflect the typical experiences of the majority of the receptor group (e.g. how many hours per day or days per year someone is exposed).

It is acknowledged that individual human behaviours vary within any group and therefore exposure has also been evaluated using both typical exposure parameters and upper estimates of exposure parameters. The upper estimate approach is likely to only apply to a few individuals for some pathways. The exposure parameters and adopted PFAS concentrations were based on typical and upper estimate exposures as defined here:

- Typical scenarios are based on a mixture of average or maximum (i.e. 365 days per year) exposure parameters and average exposure concentrations. This results in a conservative estimate of the average population exposure and is likely to represent most of the population. As an example, it was assumed adults would drink 2 litres of water containing average concentrations of PFAS measured in each water source, every day over their adult life.
- Upper estimate scenarios are based on a mixture of upper estimates (i.e. the 90th percentile) and maximum exposure parameters, and the upper estimate of PFAS concentrations in food or water consumed, resulting in a cumulative overestimate of exposures. The scenario not likely to be representative for many individuals in the population. For example, it was assumed adults would drink 10 litres of water containing 90th percentile concentrations of PFAS measured in each water source, for every day over their adult life.

Adults and young children were evaluated separately, as the relative intake for young children (aged 0 to 6 years) is known to differ from older children and adults based on weight to contaminant intake ratios and behavioural patterns.

Risk characterisation

The potential intake of PFOS, PFHxS and PFOA was estimated from various exposure pathways, based on the reported concentrations in soils, sediments, waters and biota, and by considering likely and high end exposure scenarios. Each plausible pathway was assessed either by screening against available screening levels, or by quantification.

The risk from PFAS exposure is expressed in terms of a Hazard Index (HI). The HI is the ratio of the estimated exposure in terms of chronic daily intakes, to the tolerable daily intakes for all chemicals and pathways to a given receptor. Where HI is less than 1, there is unlikely to be any adverse health effects associated with exposure to the chemicals of concern. However, a HI exceeding 1 does not necessarily indicate an actual risk but rather a potential adverse health outcome requiring additional assessment.

A summary of risk of elevated exposure to PFAS compounds is presented in the tables below in terms of "Low & acceptable", "Marginal" and "Elevated". Elevated indicates that the estimated exposure by that pathway is likely to exceed the Tolerable Daily Intake (TDI) and has an HI of greater than 1. Marginal indicates that the estimated intake represents more the 50% of the TDI (HI between 0.5 and 1), and may result in exceedance of the TDI when combined with other pathways. Low & acceptable indicates that the estimated exposure does not exceed the TDI and has an HI of less than 0.5.

Table 1 to Table 3 summarise the outcomes of the risk assessment for on-Base and off-Base workers in commercial, maintenance and construction settings. Table 4 summarises the risk of elevated exposure for on-Base and off-Base residents, and Table 5 and Table 6 summarises the risk of elevated exposure for recreational users of Rapid, Ludmilla, Sadgroves and Reichardt creeks.

Table 1: Summary of risk of elevated exposure – Commercial / Industrial

Potential Exposure Pathway	Method of assessment	On-base workers and/or visitors including DIA workers (commercial/industrial)		Off-base workers (commercial/industrial)	
		Typical	Upper estimate	Typical	Upper estimate
Incidental ingestion of surface soil	Screen / Quantify	Low & acceptable	Low & acceptable	Low & acceptable	Low & acceptable
Dermal contact with surface soil	Screen / Quantify	Low & acceptable	Low & acceptable	Low & acceptable	Low & acceptable
Inhalation of dusts derived from contaminated soils	Quantify	Low & acceptable	Low & acceptable	Low & acceptable	Low & acceptable
Incidental ingestion and/or dermal contact of surface water and sediments	Screen / Quantify	Low & acceptable	Low & acceptable	Low & acceptable	Low & acceptable

Table 2: Summary of risk of elevated exposure – Maintenance workers (max. 1 m excavation)

Potential Exposure Pathway	Method of assessment	On-base maintenance workers		Off-base maintenance workers - DIA		Off-base maintenance workers - Other off-base areas	
		Typical	Upper estimate	Typical	Upper estimate	Typical	Upper estimate
Incidental ingestion of surface and excavated soil from contaminated areas	Screen	Low & acceptable	Low & acceptable	Low & acceptable	Low & acceptable	Low & acceptable	Low & acceptable
Dermal contact with surface and excavated soil from contaminated areas	Screen	Low & acceptable	Low & acceptable	Low & acceptable	Low & acceptable	Low & acceptable	Low & acceptable
Inhalation of dusts derived from contaminated soils	Quantify	Low & acceptable	Low & acceptable	Low & acceptable	Low & acceptable	Low & acceptable	Low & acceptable
Dermal contact and/or incidental ingestion of surface water and sediments	Screen	Low & acceptable	Low & acceptable	Low & acceptable	Low & acceptable	Low & acceptable	Low & acceptable
Incidental ingestion and/or dermal contact of intercepted contaminated groundwater	Screen	Low & acceptable	Low & acceptable	Low & acceptable	Low & acceptable	Low & acceptable	Low & acceptable
Incidental ingestion of effluent water from contaminated infrastructure	Quantify	Low & acceptable	Elevated	NA	NA	NA	NA
Dermal contact with effluent water from contaminated infrastructure	Quantify	Low & acceptable	Low & acceptable	NA	NA	NA	NA

NA – Pathway incomplete or not relevant

Table 3: Summary of risk of elevated exposure – Construction workers (greater than 1 m deep excavation)

Potential Exposure Pathway	Method of assessment	On-Base construction workers		Off-Base construction workers - DIA		Off-Base construction workers - Other off-Base areas	
		Typical	Upper estimate	Typical	Upper estimate	Typical	Upper estimate
Incidental ingestion of surface and excavated soil from contaminated areas	Screen / Quantify	Low & acceptable	Low & acceptable	Low & acceptable	Low & acceptable	Low & acceptable	Low & acceptable
Dermal contact with surface and excavated soil from contaminated areas	Screen / Quantify	Low & acceptable	Low & acceptable	Low & acceptable	Low & acceptable	Low & acceptable	Low & acceptable
Inhalation of dusts derived from contaminated soils	Quantify	Low & acceptable	Low & acceptable	Low & acceptable	Low & acceptable	Low & acceptable	Low & acceptable
Incidental ingestion of intercepted contaminated groundwater	Quantify	Low & acceptable	Elevated	Low & acceptable	Elevated	Low & acceptable	Low & acceptable
Dermal contact with intercepted contaminated groundwater	Quantify	Low & acceptable	Low & acceptable	Low & acceptable	Low & acceptable	Low & acceptable	Low & acceptable

Table 4: Summary of risk of elevated exposure – Residents

Potential Exposure Pathway	Method of assessment	On-Base residents (within accommodation areas)		Off-Base residents to the north Relevant suburbs: Jingili & Millner		Off-Base residents to the west Relevant suburbs: Bagot		Off-Base residents to the south Relevant suburb: The Narrows	
		Typical	Upper estimate	Typical	Upper estimate	Typical	Upper estimate	Typical	Upper estimate
Incidental ingestion of surface soil	Screen	Low & acceptable	Low & acceptable	Low & acceptable	Low & acceptable	Low & acceptable	Low & acceptable	Low & acceptable	Low & acceptable
Dermal contact with surface soil	Screen	Low & acceptable	Low & acceptable	Low & acceptable	Low & acceptable	Low & acceptable	Low & acceptable	Low & acceptable	Low & acceptable
Inhalation of dusts derived from contaminated soils	Quantify	Low & acceptable	Low & acceptable	Low & acceptable	Low & acceptable	Low & acceptable	Low & acceptable	Low & acceptable	Low & acceptable
Incidental ingestion and/or dermal contact of surface water and sediments	Screen	Low & acceptable	Low & acceptable	Low & acceptable	Low & acceptable	Low & acceptable	Low & acceptable	Low & acceptable	Low & acceptable
Ingestion of fruit, vegetables or native plants that are irrigated with, or have root systems in impacted groundwater	Screen	NA	NA	Low & acceptable	Low & acceptable	Low & acceptable	Low & acceptable	Low & acceptable	Low & acceptable
Ingestion of water while swimming in pools filled with impacted bore water	Quantify	NA	NA	Low & acceptable	Low & acceptable	Low & acceptable	Elevated for children only	Low & acceptable	Low & acceptable
Dermal contact with water while swimming in pools filled with impacted bore water	Quantify	NA	NA	Low & acceptable	Low & acceptable	Low & acceptable	Low & acceptable	Low & acceptable	Low & acceptable
Ingestion of water during outdoor activities with impacted bore water	Quantify	NA	NA	Low & acceptable	Low & acceptable	Low & acceptable	Elevated for children only	Low & acceptable	Low & acceptable
Dermal contact during outdoor activities with impacted bore water	Quantify	NA	NA	Low & acceptable	Low & acceptable	Low & acceptable	Low & acceptable	Low & acceptable	Low & acceptable
Ingestion of home-grown eggs from poultry watered with impacted bore water	Screen / Quantify	NA	NA	Low & acceptable	Low & acceptable	Marginal	Elevated	Low & acceptable	Low & acceptable

NA – Pathway incomplete or not relevant

Table 5: Summary of risk of elevated exposure – Recreational users of creeks

Potential Exposure Pathway	Method of assessment	Recreational users of Rapid Creek		Recreational users of Upper Ludmilla Creek (East of Dick Ward Drive)		Recreational users of Estuarine Ludmilla Creek	
		Typical	Upper estimate	Typical	Upper estimate	Typical	Upper estimate
Incidental ingestion of surface water during swimming	Screen / Quantify	Low & acceptable	Low & acceptable	Low & acceptable	Elevated	Low & acceptable	Low & acceptable
Dermal contact with surface water during swimming	Screen / Quantify	Low & acceptable	Low & acceptable	Low & acceptable	Low & acceptable	Low & acceptable	Low & acceptable
Dermal contact and/or incidental ingestion of sediment during swimming	Screen	Low & acceptable	Low & acceptable	Low & acceptable	Low & acceptable	Low & acceptable	Low & acceptable

Table 5: Summary of risk of elevated exposure – Consumers of aquatic biota

Potential Exposure Pathway	Method of assessment	Consumers of aquatic biota from the freshwater portion of Rapid Creek		Consumers of aquatic biota from the estuarine portion of Rapid Creek		Consumers of aquatic biota from Ludmilla Creek		Consumers of aquatic biota from Darwin Harbour, Sadgroves Creek or Reichardt Creek	
		Typical	Upper estimate	Typical	Upper estimate	Typical	Upper estimate	Typical	Upper estimate
Ingestion of fish	Screen	Elevated	Elevated	Low & acceptable	Elevated	Low & acceptable	Elevated	Low & acceptable	Low & acceptable
Ingestion of crustaceans	Screen	Low & acceptable	Elevated	Low & acceptable	Elevated	Low & acceptable	Elevated	Low & acceptable	Low & acceptable
Ingestion of molluscs	Quantify	NA	NA	Low & acceptable	Elevated	Low & acceptable	Elevated	Low & acceptable	Low & acceptable

NA – Pathway incomplete or not relevant

Based on the available data, exposure assumptions and constraints of the exposure assessment model used, health risks associated with PFAS compounds identified in soil, groundwater, surface waters and terrestrial and aquatic biota, as presented in this report, are as follows:

- For the scenarios modelled using **typical exposure** inputs, a total HI of less than 1, indicating low and acceptable exposure, was estimated for all receptors with the exception of the following scenarios:
  - Off-Base young children (2 to 6yo) residents of Bagot, where bore water was used for non-potable domestic uses, were calculated to have a total HI of 1.1 based on typical exposure. The most significant contributing pathway to this was ingestion of poultry eggs where groundwater was used to water the livestock (HI of 0.91).

    For any children not exposed to poultry eggs where groundwater was used to water the livestock, the calculated health risk would be low and acceptable. The calculated health risks to adult receptors was low and acceptable for all pathways.
  - Consumers of freshwater aquatic biota caught from Rapid Creek calculated to have a total HI of 5.9 for young children and 2.4 for older children and adults based on typical exposure (one serve per month). The most significant contributing pathway to this was ingestion of finfish (HI of 5.7 and 2.3 respectively).
- For the scenarios modelled using **upper estimate** exposure inputs, a total HI of less than 1, indicating low and acceptable exposure, was estimated for the following receptors:
  - Base personnel and DIA workers;
  - On-Base residents;
  - Off-Base commercial and industrial workers;
  - Off-Base and DIA land intrusive maintenance workers;
  - Off-Base construction (excavation) workers;
  - Off-Base residents of The Narrows (regardless of bore water use);
  - Off-Base residents of Millner and Jingili (regardless of bore water use);
  - Off-Base recreational swimmers in the estuarine area of Ludmilla Creek;
  - Off-Base recreational swimmers in the freshwater area of Rapid Creek;
  - Consumers of aquatic biota caught in Darwin Harbour including Sadgroves and Reichardt creeks.
- For the scenarios modelled using **upper estimate** exposure inputs, a total HI of greater than 1, indicating a potential health risk, was estimated for the following receptors. As the Total HI is dependent on all pathways being relevant to the specific receptor, additional details are provided below:
  - On-base maintenance workers were calculated to have a total HI of 2.9 based on the upper estimate exposure. The most significant contributing pathway to this was accidental ingestion of effluent water from contaminated infrastructure (HI of 2.3).

    For any maintenance worker not exposed to effluent water, the calculated health risk would be low and acceptable. It is considered unlikely that the upper exposure estimates would be realised with appropriate workplace health and safety procedures;
  - On-Base construction (excavation) workers were calculated to have a total HI of 9.5 based on the upper estimate exposure. The most significant contributing pathway to this was accidental ingestion of groundwater (HI of 9.1), based on the most heavily contaminated area on Base.

    For any construction worker not exposed to groundwater, the calculated health risk would be low and acceptable;

- Off-Base construction (excavation) workers on DIA land were calculated to have a total HI of 1.3 based on the upper estimate exposure. The most significant contributing pathway to this was accidental ingestion of groundwater (HI of 1.3).

  For any construction worker not exposed to groundwater, the calculated health risk would be low and acceptable;

- Off-Base residents of Bagot where bore water was used for non-potable domestic purposes were calculated to have a total HI of 11 for young and an HI of 3.1 for older children and adults, based on the upper estimate exposure. For children aged less than 6, the most significant contributing pathways to this was accidental ingestion of extracted groundwater whilst swimming (HI of 3.3) and during sprinkler play (HI of 1.7) and the ingestion of poultry eggs where groundwater was used to water the livestock (HI of 6.2). For older receptors the most significant exposure pathway was the ingestion of poultry eggs where groundwater was used to water the livestock (HI of 2.2).

  Use of bore water has been flagged as a potential use only. There are no known groundwater users west of the Base. Where groundwater extraction is not a valid pathway, the calculated health risk would be low and acceptable;

- Off-Base recreational swimmers aged less than 6 in the upper reaches of Ludmilla Creek were calculated to have a total HI of 1.8 based on the upper estimate exposure. The calculated health risks to adult receptors was low and acceptable.

  Coffey notes that sampling in this area was predominantly conducted in accessible stormwater drains close to Bagot Road and that the main Ludmilla Creek is relatively inaccessible in this area;

- Based on upper estimate exposures (assumed one serve per week), the calculated HIs for consumers of aquatic biota from both Ludmilla and Rapid creeks were all greater than 1. Children aged less than 6 were identified as being more at risk than older receptors. Consumers were more at risk consuming aquatic biota from the freshwater section of Rapid Creek than the estuarine section of the creek.

Management Options

Where off-Base activities have been indicated to potentially lead to elevated exposure to PFAS, the assessment and direct concentration data has been referred to NT government agencies to assess the need and mechanism of management actions or warning advice to reduce exposure to receptors in the short term. Management actions are also being reviewed for on-Base activities that could reduce Base contribution to PFAS contamination.

For on-Base scenarios, occupational health and safety controls should be implemented for maintenance workers conducting work on the waste water infrastructure at the Current Fire Training Ground and for excavation workers who may come in contact with groundwater in the vicinity of the PFAS source areas. Control measures should aim to reduce incidental ingestion of groundwater.

Limitations

The risk assessment has been limited to addressing the impacts of selected substances, to a specific assumed receptor population under a defined exposure scenario, based on information available at the time of the assessment. The risk assessment approach presented does not consider a fully probabilistic estimate of risk, but presents conditional estimates based on a number of assumptions regarding exposure and toxicity consistent with the nationally endorsed regulatory approach. Further assessments would be required to assess risk where site uses vary from the assumed site conditions and/or exposure settings used in this risk assessment.

This executive summary must be read in conjunction with the body of the report and the limitations described in the attached “Important Information about your Coffey Environmental Report”.

Important information about your **Coffey** Environmental Report

Introduction

This report has been prepared by Coffey for you, as Coffey's client, in accordance with our agreed purpose, scope, schedule and budget.

The report has been prepared using accepted procedures and practices of the consulting profession at the time it was prepared, and the opinions, recommendations and conclusions set out in the report are made in accordance with generally accepted principles and practices of that profession.

The report is based on information gained from environmental conditions (including assessment of some or all of soil, groundwater, vapour and surface water) and supplemented by reported data of the local area and professional experience. Assessment has been scoped with consideration to industry standards, regulations, guidelines and your specific requirements, including budget and timing. The characterisation of site conditions is an interpretation of information collected during assessment, in accordance with industry practice,

This interpretation is not a complete description of all material on or in the vicinity of the site, due to the inherent variation in spatial and temporal patterns of contaminant presence and impact in the natural environment. Coffey may have also relied on data and other information provided by you and other qualified individuals in preparing this report. Coffey has not verified the accuracy or completeness of such data or information except as otherwise stated in the report. For these reasons the report must be regarded as interpretative, in accordance with industry standards and practice, rather than being a definitive record.

Your report has been written for a specific purpose

Your report has been developed for a specific purpose as agreed by us and applies only to the site or area investigated. Unless otherwise stated in the report, this report cannot be applied to an adjacent site or area, nor can it be used when the nature of the specific purpose changes from that which we agreed.

For each purpose, a tailored approach to the assessment of potential soil and groundwater contamination is required. In most cases, a key objective is to identify, and if possible quantify, risks that both recognised and potential contamination pose in the context of the agreed purpose. Such risks may be financial (for example, clean up costs or constraints on site use) and/or physical (for example, potential health risks to users of the site or the general public).

Limitations of the Report

The work was conducted, and the report has been prepared, in response to an agreed purpose and scope, within time and budgetary constraints, and in reliance on certain data and information made available to Coffey.

The analyses, evaluations, opinions and conclusions presented in this report are based on that purpose and scope, requirements, data or information, and they could change if such requirements or data are inaccurate or incomplete.

This report is valid as of the date of preparation. The condition of the site (including subsurface conditions) and extent or nature of contamination or other environmental hazards can change over time, as a result of either natural processes or human influence. Coffey should be kept appraised of any such events and should be consulted for further investigations if any changes are noted, particularly during construction activities where excavations often reveal subsurface conditions.

In addition, advancements in professional practice regarding contaminated land and changes in applicable statues and/or guidelines may affect the validity of this report. Consequently, the currency of conclusions and recommendations in this report should be verified if you propose to use this report more than 6 months after its date of issue.

The report does not include the evaluation or assessment of potential geotechnical engineering constraints of the site.

Interpretation of factual data

Environmental site assessments identify actual conditions only at those points where samples are taken and on the date collected. Data derived from indirect field measurements, and sometimes other reports on the site, are interpreted by geologists, engineers or scientists to provide an opinion about overall site conditions, their likely impact with respect to the report purpose and recommended actions.

Variations in soil and groundwater conditions may occur between test or sample locations and actual conditions may differ from those inferred to exist. No environmental assessment program, no matter how comprehensive, can reveal all subsurface details and anomalies. Similarly, no professional, no matter how well qualified, can reveal what is hidden by earth, rock or changed through time.

The actual interface between different materials may be far more gradual or abrupt than assumed based on the facts obtained. Nothing can be done to change the actual site conditions which exist, but

steps can be taken to reduce the impact of unexpected conditions.

For this reason, parties involved with land acquisition, management and/or redevelopment should retain the services of a suitably qualified and experienced environmental consultant through the development and use of the site to identify variances, conduct additional tests if required, and recommend solutions to unexpected conditions or other unrecognised features encountered on site. Coffey would be pleased to assist with any investigation or advice in such circumstances.

Recommendations in this report

This report assumes, in accordance with industry practice, that the site conditions recognised through discrete sampling are representative of actual conditions throughout the investigation area. Recommendations are based on the resulting interpretation.

Should further data be obtained that differs from the data on which the report recommendations are based (such as through excavation or other additional assessment), then the recommendations would need to be reviewed and may need to be revised.

Report for benefit of client

Unless otherwise agreed between us, the report has been prepared for your benefit and no other party. Other parties should not rely upon the report or the accuracy or completeness of any recommendation and should make their own enquiries and obtain independent advice in relation to such matters.

Coffey assumes no responsibility and will not be liable to any other person or organisation for, or in relation to, any matter dealt with or conclusions expressed in the report, or for any loss or damage suffered by any other person or organisation arising from matters dealt with or conclusions expressed in the report.

To avoid misuse of the information presented in your report, we recommend that Coffey be consulted before the report is provided to another party who may not be familiar with the background and the purpose of the report. In particular, an environmental disclosure report for a property vendor may not be suitable for satisfying the needs of that property's purchaser. This report should not be applied for any purpose other than that stated in the report.

Interpretation by other professionals

Costly problems can occur when other professionals develop their plans based on misinterpretations of a report. To help avoid misinterpretations, a suitably qualified and experienced environmental consultant should be retained to explain the implications of the report to other professionals referring to the report and then review plans and specifications produced to see how other professionals have incorporated the report findings.

Given Coffey prepared the report and has familiarity with the site, Coffey is well placed to provide such assistance. If another party is engaged to interpret the recommendations of the report, there is a risk that the contents of the report may be misinterpreted and Coffey disowns any responsibility for such misinterpretation.

Data should not be separated from the report

The report as a whole presents the findings of the site assessment and the report should not be copied in part or altered in any way. Logs, figures, laboratory data, drawings, etc. are customarily included in our reports and are developed by scientists or engineers based on their interpretation of field logs, field testing and laboratory evaluation of samples. This information should not under any circumstances be redrawn for inclusion in other documents or separated from the report in any way.

This report should be reproduced in full. No responsibility is accepted for use of any part of this report in any other context or for any other purpose or by third parties.

Responsibility

Environmental reporting relies on interpretation of factual information using professional judgement and opinion and has a level of uncertainty attached to it, which is much less exact than other design disciplines. This has often resulted in claims being lodged against consultants, which are unfounded. As noted earlier, the recommendations and findings set out in this report should only be regarded as interpretive and should not be taken as accurate and complete information about all environmental media at all depths and locations across the site.

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