Stage 3 Risk Assessment and Remediation Design at Army Aviation Centre Oakey
Remediation Action Plan - Perfluorocarbons in Groundwater

June 2013

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# Glossary

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<td>Army Aviation Centre Oakey</td>
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<td>AFFF</td>
<td>Aqueous Film Forming Foam</td>
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<td>COPC</td>
<td>Chemical of Potential Concern</td>
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<td>CRAT</td>
<td>Contamination Risk Assessment Tool</td>
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<td>CSM</td>
<td>Conceptual Site Model</td>
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<td>DSRG</td>
<td>Department of Defence, Defence Support and Reform Group</td>
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<td>ERA</td>
<td>Ecological Risk Assessment</td>
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<td>EPBC Act</td>
<td>Environment Protection and Biodiversity Conservation Act 1999</td>
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<td>FiS</td>
<td>Fluorotelomer Sulfonate</td>
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<td>HHRA</td>
<td>Human Health Risk Assessment</td>
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<td>mBGL</td>
<td>Metres Below Ground Level</td>
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<td>MDH</td>
<td>Minnesota Department of Health</td>
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<td>MNA</td>
<td>Monitored Natural Attenuation</td>
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<td>NSZD</td>
<td>Natural Source Zone Depletion</td>
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<td>PFAA</td>
<td>Perfluorinated Alkyl Acid</td>
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<td>PFC</td>
<td>Perfluorocarbon</td>
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<td>PFOA</td>
<td>Perfluorooctanoic Acid</td>
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<td>PFOS</td>
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<td>RA</td>
<td>Risk Assessment</td>
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<td>Remedial Action Plan</td>
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<td>RFI</td>
<td>Request for Information</td>
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<td>Standing Water Level</td>
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<td>TDS</td>
<td>Total Dissolved Solids</td>
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<td>UPSS</td>
<td>Underground Petroleum Storage tank System</td>
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<td>USEPA</td>
<td>United States Environmental Protection Agency</td>
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<td>UST</td>
<td>Underground Storage Tank</td>
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Executive summary

Parsons Brinckerhoff Australia Pty Ltd (Parsons Brinckerhoff) has been retained by the Department of Defence, Defence Support and Reform Group (DSRG, referred to hereafter as Defence) as Lead Consultant (AZ5293) to provide a remediation action plan for perfluorocarbons (PFCs) at the Army Aviation Centre Oakey (AACO) – Southern Queensland Region.

The objective of the RAP is to outline an approach and methodology to monitor groundwater quality at the site and to remove, control or eliminate perfluorocarbon (PFC) chemicals to levels which are considered safe for human health and the environment.

Remediation goals

The general clean-up goals for PFCs are as follows:

- Mitigation of risk (human health or other risks) from water supply well impacts, despite the existing risk assessment reports not identifying unacceptable risks to end-users (e.g. on-site irrigation bores, 66 Orr Road pool/irrigation bore).
- Management of potential risk to ecological receptors from irrigation bores and discharge to surface streams.

The specific remediation goal concentrations (point-of-use) for PFOS and PFOA in raw drinking water supplies will be the drinking water guidelines of 0.3 µg/L.

Mitigation of risk to water supply well receptors

No unacceptable human health risks from PFCs have been identified at AACO or in the adjacent water supply wells, based on the information available. Point-of-use remedial options have been examined in the event that remedial action is required in the future. The preferred remedial option for any water supply well user perceived to be at-risk is to provide an alternative water supply. Should alternative water supplies be technical infeasible or disagreeable to the owner or user, filtration should be considered. For a residential water supply well that can’t be decommissioned, the RAP has identified granular activated carbons as the preferred filter media to remove PFCs.

Management of risk to ecological receptors

Given that PFCs are not able to be remediated in-situ and PFCs are not readily extractable from the aquifer, monitored natural attenuation (MNA) will be pursued as the most cost effective strategy to manage risks to ecological receptors. Unacceptable risks have not been identified, based on the limited information available. A proposed MNA sampling plan is provided within the RAP. MNA contingency measures have been established to control and mitigate any potential risks. Contingency measures include additional ecological risk assessment and resource access/use restrictions.

Recommendations

It is recommended to complete delineation of PFC impacted groundwater to the west and southwest of the site. Completions of assessment activities will allow examination of other potential receptors to determine if further remediation is required.
1. Introduction

1.1 Background

Parsons Brinckerhoff Australia Pty Ltd (Parsons Brinckerhoff) has been retained by the Department of Defence, Defence Support and Reform Group (DSRG, referred to hereafter as Defence) as Lead Consultant (AZ5293) to provide a remediation action plan for perfluorocarbons (PFCs) in groundwater at the Army Aviation Centre Oakey (AACO) – Southern Queensland Region. The AACO was renamed as the Swartz Barracks during 2011; however, it will be referred to as AACO for reporting purposes to provide continuity.

Aqueous fire fighting foam (AFFF) containing perfluorocarbons (PFCs) is present in groundwater over a large area, including Areas A2, B1, B2, B3, B4, B5, C1, C2, C3, F1 and off-site (PB 2012).

1.2 Objective

The objective of the RAP is to outline an approach and methodology to monitor groundwater quality at the site and to remove, control or eliminate PFC chemicals to levels which are considered safe for human health and the environment. The RAP also provides recommendations for further groundwater assessment works.

As part of the Remediation Options Feasibility Study (PB 2013e) an evaluation of remedial technologies was undertaken which included all known potential remedial options that may be applied at AACO. All technologies were screened with respect to technical feasibility, financial considerations, logistical constraints, on-going management requirements and timing. The recommendations of the ROFS report provided preferred solutions for the control (risk management) of PFCs in groundwater and PFCs in water supplies.

1.3 Scope of works

In general, the PFC RAP is to provide a defined strategy for PFC chemical impacts onsite and offsite, which would be suitable for defining a future request for tender. The RAP includes:

- a summary of the site condition and surrounding environment
- a summary of the contamination status of the site
- assessment of data gaps that may require further investigation
- identification of remediation goals and approach
- site management issues
- contingency management; and
- occupational health and safety issues.
2. Site background information

2.1 Site location

The Queensland town of Oakey is located 3 km to the south of the AACO (Figure 1, Appendix A). The land use surrounding the AACO is predominantly agricultural (Rural – R1 planning scheme designation) with the exception of rural residential properties (RR1, Precinct 1 planning scheme designation) and Oakey Showgrounds (council land) to the south and south west. All surrounding properties are within the Toowoomba Regional Planning Scheme. The R1 designation has a 100 hectare minimum lot size, and the RR1 designation has a 4,000 square metre minimum lot size.

Over 2,000 personnel may be present at the site, including Australian Defence Force (ADF) members, civilian Defence employees, civilian logistics and support staff, and members of the Republic of Singapore Air Force (RSAF). A portion of the site is also used as an aircraft museum that is open to the public. A small and variable percentage of personnel reside on site, where there are food and recreation facilities, including a swimming pool. A large portion of land in the northwest of the airfield is leased for agricultural production (e.g. corn, cotton). The agricultural production lies within the AACO perimeter fence (yellow dashed line, Figure 2, Appendix A), but outside the internal airfield security fence (green dashed line, Figure 2, Appendix A). Historical crop types are not known, but crop rotation is expected.

2.2 Historical land use

Based on previous Phase 1 Environmental Site Assessments, the AACO site has been utilised as a military and civilian airport since the 1940s (URS 2010). During World War II, the site was occupied by the Royal Australian Air Force (URS 2010). From 1948 to 1969 the site was used as a civilian airfield, after which, Defence purchased the site for use as AACO (URS 2010). The site has been and is still used for the maintenance of aircraft, fuelling of aircraft and vehicles, as well as other potential polluting military and industrial activities (e.g. waste lagoon, landfill, fuel underground storage tanks (USTs), waste hydrocarbon USTs, fire training areas and interceptor traps).

2.3 Timeline of Environmental Investigations

A summary of the previous environmental investigations that are relevant to this RAP is provided below, where information is known to Parsons Brinckerhoff:
2.3.1  1991


This document provides earliest record of waste disposal practices at the site. No figures were available for review. Numerous clay-lined pits and historic spills were identified at the site.

*Army Pollution Audits – Queensland, Volume 2, Detailed Report, Kinhill Engineers Pty Ltd 1991.*

A site inspection identified a recently installed 1,000L waste oil tank in Area C1 for the collection of hydraulic oil, detergent and fuel. A deficiency was noted that the tank levels were checked manually at the request of the disposal company, and that this could lead to tank overflows. Likewise, a leak would not likely be detected without routine on-site tank monitoring. The report went on to note that substantial ground movements were noted to occur at the site, where cracking of pipes had occurred. A deficiency was noted that specific design measures were required to prevent rupture or disconnect from the Building C2 waste oil UST.

2.3.2  1997

*Remediation of Old Fire Training Area for Army Aviation Centre – Oakey, Thiess Environmental Services 1997.*

Hydrocarbon impacted soil was removed from the former Fire Pit and ‘landfarmed’ adjacent to the excavation. One UST at the Fire Pit was removed for off-site disposal. No assessment was undertaken for PFCs.

2.3.3  2009


An investigation of potentially leaking infrastructure was organised by Spotless on behalf of Defence. Reports of oil flowing into the oil-water separator outlet connection and oil floating in the adjacent AFFF storage tank were investigated. Both underground tanks were found to be constructed of reinforced concrete. The causes of the oil ingress were suggested to be caused by subsidence related oil-water separator chamber and pipe cracking, as well as a faulty pipe seal on the AFFF tank. The faulty seal would allow oil that had leaked from the oil-water separator to ingress into the AFFF tank, and may have allowed AFFF waste water to leak into the ground when fluid levels were sufficiently high.

The report recommended the replacement of the oil separator and associated piping from the Building C2 boundary. It also recommended the installation of new connections on the eastern side of the AFFF tank. No recommendations were stated for remediation of the adjacent soil.
2.3.4 2010

Stage 1 and Stage 2 Environmental Investigation at Army Aviation Centre, Oakey, Queensland. URS Australia Pty Ltd, 14 October 2010.

The Stage 1 desktop assessment by URS assessed the potential risks associated with historical and current activities conducted on the AACO by using the Contamination Risk Assessment Tool (CRAT) based on newly established areas of investigation. The area designations are used by subsequent investigations by Coffey and Parsons Brinckerhoff.

As part of the Stage 2 investigation, a total of 17 monitoring wells were installed in the Stage 2 investigation. Results of the well sampling investigation identified PSH in three wells within Area C1. The maximum PSH thickness was measured to be 0.6m. Groundwater impacts by petroleum hydrocarbons exceeded the investigation levels in four areas (C1, C2, C3 and F1). PFC (a combination of PFOS and PFOA) impacts to groundwater in excess of the investigation levels were identified in 6 wells within Area C1, and 6 wells in Area F1.

URS noted that two irrigation bores were in operation on-site for aircraft washing, irrigation and fire training purposes. They also noted that a council bore (36603) was located approximately 900m southwest of the impacted areas.

The report recommended additional assessment of activity areas relating to World War II era land use, as well as analytical testing of the closest hydraulically down-gradient extraction bores.

2.3.5 2011

Stage 2, Part 2 Environmental Investigation Army Aviation Centre Oakey. Coffey Environments Australia Pty Ltd, 9 August 2011.

Coffey advanced 75 soil bores and conducted a groundwater monitoring event utilising 82 wells. A total of 11 of 14 groundwater samples analysed for PFCs exceeded the investigation levels. A source area for PFCs in groundwater was not identified, and delineation of PFC extent was not achieved.

The report recommended investigation of storm water drains for the potential of off-site PFC transport in sediments. It also recommended a human health risk assessment and investigation of on-site extraction bores be conducted.

The CRAT was revised to list Area C1 as the only ‘very high risk’ region of the site.

2.3.6 2012

Environmental Investigation – Stage 3 Risk Assessment and Remediation Design, Army Aviation Centre Oakey (AACO), Parsons Brinckerhoff, August 2012.

The letter report assessed 10 drain sediment locations on-site for PFC, total petroleum hydrocarbon (TPH) and metals. All tested locations contained detectable concentrations of PFCs, but the concentrations were below the adopted investigation criteria concentrations.
A total of 32 monitoring wells were assessed to confirm the extent of PFCs. Results indicated the presence of PFCs, with similar concentrations and distribution in groundwater to the Coffey (2011) report. There were no new contaminants of concern identified in groundwater.

A total of 23 samples were identified to exceed the adopted investigation criteria concentrations for PFOS and/or PFOA. The highest PFOS concentrations were identified in Area B3. Area B3 formerly housed the AACO fire station and fire training area. Significantly elevated PFOS and PFOA impacts were also recorded in Area C3, Area C1 and Area S1. Delineation of the PFC plume in groundwater was not achieved to the west and south.

One aquifer test was completed in Area C1 at location MWC1-I provided a hydraulic conductivity rate of $2.6 \times 10^{-5}$ cm/sec.

Operation of on-site irrigation bores was identified to be used for the barrack’s swimming pool. Testing of irrigation bore 35453 and 35454 indicated concentrations of PFOS and PFOA in excess of the adopted criteria.

Report recommendations suggested the additional sampling of on-site monitor wells for PFC delineation, locating and testing of on-site irrigation bores for contaminants of concern, and the installation of double-cased bores in the lower alluvial aquifer to identify the potential for off-site transport of PFCs.

Neighbourhood Information Session at AACO, Department of Defence 13 December 2012

A public meeting was organised and held at AACO by Defence to provide information about PFCs in soil and water at the site. Questions and requests from the public were received by Defence.

2.3.7 2013

Stage 3 Risk Assessment and Remediation Design at Army Aviation Centre Oakey - Groundwater Monitoring Event, December 2012, Parsons Brinckerhoff, February 2013

The primary objective of the groundwater monitoring event was to assess the environmental conditions of groundwater utilising the existing monitoring well network. Secondary objectives included characterising the extent of PFC impacts to soil, groundwater and water supply systems.

PFC impacts

PFOS and PFOA concentrations at numerous monitoring wells were identified above the adopted criteria in groundwater. The highest concentration of PFOS was identified in Area B3. High PFOS and PFOA impacts were also recorded in Area F1, Area C1, Area S1 and Area B1.

The extent of PFC impacts to the upper alluvial aquifer above the adopted criteria was generally delineated on the south-eastern and southern sides of the site. Down hydraulic gradient delineation of the upper alluvial aquifer (northwest) had not been achieved as concentrations of PFOS in Area A2 appear to fluctuate above the adopted criteria during some monitoring events.
PFC impacts to the lower alluvial aquifer above the adopted criteria were confirmed at onsite and off-site locations.

**Drainage Channel Soil Sediment Findings**

The drainage channel sediment assessment results identified concentrations of PFOS below the adopted criteria at all drainage channel sediment locations. PFOA was only identified in one soil sample below the adopted criteria at location SS011, near the AACO site boundary. Further assessment of off-site drainage sediments for PFOS and PFOA was concluded not to be warranted.

**Water Supply System Assessments**

Sampling of on-site irrigation bores (35453 and 35454) identified PFOS at concentrations in excess of the adopted drinking water guidelines. Further investigation identified that the on-site hydrant system and irrigation system contains PFOS at concentrations above the adopted drinking water guidelines. Additionally, the pool was determined to utilise irrigation water for re-filling purposes. Several samples of pool water indicate consistent concentrations of PFOS above the adopted drinking water guidelines.

There are two irrigation bores, 83264 and 66256, which are located on leased property towards the west of Area A1 and A2 (Figure 2, Appendix A). These bores are periodically used for crop irrigation, typically one month per year (January-February).

The water supply bore owned by Toowoomba Regional Council (36603) is located approximately 10m west of monitoring well location MWA4-A. The laboratory results from well MWA4-A indicated an exceedence of PFOS guidelines in the groundwater. This data indicated that PFOS may have impacted the council bore.

A private water supply system at 66 Orr Road has also been impacted. This bore supplies brackish water for landscape irrigation and pool water supply. PFOS concentrations have been identified to be above the drinking water criteria.

**Addendum to Stage 3 Risk Assessment and Remediation Design at Army Aviation Centre Oakey Groundwater Monitoring Event, Parsons Brinckerhoff, May 2013.**

Groundwater impacts from PFCs were identified in laboratory results from the analysis of two off-site irrigation bore samples (66256 and 83264) in the lower alluvial aquifer that are seasonally operated.

Delineation to the northwest of PFC impacts in groundwater was achieved after groundwater sampling of the site bore 35893. Delineation of the PFC plume towards the west and southwest has not been achieved.

Four monitoring wells located at the site boundary were tested for the second time, which confirmed concentrations of PFCs above the adopted investigation levels at three of 4 locations. While concentrations at location MWA4-A were identified slightly below the adopted criteria, the proximity to a drinking water supply well indicate ongoing monitoring of location MWA4-A is advisable.
Onsite Risk Assessment, PFOS and PFOA in Groundwater: Stage 3 Risk Assessment and Remediation Design, Army Aviation Centre Oakey, May 2013

The objective of the Risk Assessment (RA) was to assess the potential for unacceptable risks to human health following:

- Incidental ingestion of groundwater impacted by PFOS and PFOA by adult and child base residents during swimming in the AACO pool.

- Incidental ingestion of groundwater impacted by PFOS and PFOA by adult Defence personnel who may be responsible for undertaking irrigation activities at the site.

- Incidental ingestion of groundwater impacted by PFOS and PFOA by adult and child base residents, who may be exposed to groundwater used for irrigation activities.

In addition, a Screening Ecological Risk Assessment (ERA) comprising the problem identification phase was undertaken to assess the potential for unacceptable risks to ecological health following the discharge of groundwater impacted with PFOS and PFOA into the site environment.

The HHRA concluded that:

- The Hazard Indices (HI) for the onsite populations and exposure pathways of concern were below the tolerable threshold (ie. HI <1), indicating that adverse health effects from exposure to PFOS and PFOA concentrations in groundwater onsite to the populations of concern are unlikely.

The Screening ERA concluded that:

- In 2002, two significant ecosystems, three recognised flora species and 11 fauna species of conservation significance, were identified to occur, or were considered to have a moderate to high probability of occurring at AACO. Other threatened species, or habitat for these species, may be present at AACO. The flora and fauna species may be adversely affected by the use of groundwater containing PFOS and PFOA for irrigation activities at the site. The likelihood of adverse effect is unable to be determined based on existing information.

Based on the preliminary findings of the Screening ERA, Parsons Brinckerhoff recommends that a higher level (ie. Level 2) ERA is undertaken. This Level 2 ERA may include the following:

- A site visit by an ecologist to re-affirm the environmental values identified in the screening ERA (eg. species of conservation significance) given the time elapsed since the last biodiversity assessment (ie. IT Environmental, 2002).

- Desktop study to identify what information is available in the scientific literature regarding benchmark doses for species similar to those that have been identified onsite and source-receptor-pathways for the uptake of PFCs into the site ecological food chain. This will allow the conceptual site model (CSM) for ERA to be refined and any critical exposure pathways for key species identified.
Offsite Risk Assessment, PFOS and PFOA in Groundwater: Stage 3 Risk Assessment and Remediation Design, Army Aviation Centre Oakey, May 2013

The RA comprised a Human Health Risk Assessment (HHRA) and a Screening Ecological Risk Assessment (ERA).

The objective of the HHRA was to assess the potential for unacceptable risks to human health following:

- Incidental ingestion of groundwater impacted by PFOS and PFOA by adult and child residents during swimming in the pool at 66 Orr Road, Oakey. 66 Orr Road is located approximately 500 m to the southwest of the AACO gatehouse (ie. offsite).

- Incidental ingestion of groundwater impacted by PFOS and PFOA by adult farm workers who may be responsible for undertaking irrigation activities at properties to the west and south of the site.

- Incidental ingestion of groundwater impacted by PFOS and PFOA by adult and child residents, who may be exposed to groundwater used for irrigation activities at properties to the west and south of the site (ie. incidental exposure).

The objective of the Screening ERA was to assess the potential for unacceptable risks to identified offsite ecosystems following the discharge of groundwater impacted with PFOS and PFOA into the environment.

The HHRA concluded that:

- The estimated Hazard Indices (HI) were below the tolerable threshold (i.e. HI <1). This indicated that adverse health effects from exposure to PFOS and PFOA concentrations in groundwater offsite, for the offsite populations and exposure pathways of concern, are unlikely.

The Screening ERA identified a potential risk to aquatic organisms (including the Environment Protection and Biodiversity Conservation (EPBC) protected Murray Cod) and birds in the event that PFOS impacts identified in groundwater to the south/west of the site migrate to, or are identified in, Oakey Creek. While the significant distance (estimated to be up to 7.2 km) from the site to the point of discharge for groundwater into Oakey Creek is noted, and dilution of groundwater upon discharge to Oakey Creek is probable, the potential for adverse impact is unable to be excluded on the basis of the existing information. This includes the potential effect of groundwater extraction events on groundwater flow rates.

In addition, four threatened ecological communities and 41 species of flora/fauna may occur or are likely to occur within a 10 km radius of the site. The flora and fauna species may be adversely affected by the use of groundwater containing PFOS and PFOA for offsite irrigation activities, or by the discharge of impacted groundwater into Oakey Creek. The likelihood of adverse effect is unable to be determined based on the existing information.
Based on the findings of the Screening ERA, Parsons Brinckerhoff recommends that a higher level (i.e., Level 2) ERA is undertaken. This Level 2 ERA may include the following:

- Delineation of groundwater impacts in the vicinity of the site and/or groundwater contaminant fate and transport, and dilution/dispersion modelling to estimate the likely PFOS/PFOA concentrations within Oakey Creek.

- Measurement of PFOS/PFOA concentrations within Oakey Creek upstream and downstream of the estimated discharge point for groundwater to the Creek.

- Biodiversity assessment in the vicinity of the site, including Oakey Creek, to confirm the environmental values identified in the Screening ERA – this includes the presence of the Murray Cod, and other threatened flora and fauna species reported to be present in the vicinity of the site.

- Further review of groundwater use in the vicinity of the site to confirm source-receptor pathways for the uptake of PFCs into the offsite ecological food chain. This will allow the CSM for ERA to be refined and any critical exposure pathways for key species identified. In the event that exposure pathways for key species are identified to be complete, a desktop study could be undertaken to determine what information is available in the scientific literature regarding benchmark doses for species similar to the identified key species.

**Stage 3 Risk Assessment and Remedy Design at Army Aviation Centre Oakey, Remediation Options Feasibility Study, Preliminary Final 2013.**

Part of the scope of the Remedial Option feasibility Study was specified to address PFCs in relation to onsite and offsite impacts. A summary of the findings relevant to PFC remediation is presented below:

**Perfluorinated Compounds (PFCs) in Groundwater and Water Supplies**

Based on the information available regarding risk to receptors from PFCs and the partly delineated extent of the PFC plume, alternative water supplies or point-of-use filtration are the only suitable risk management options for small residential water supply bores. As completion of PFC delineation in the lower alluvial aquifer and identification of any other groundwater users within the delineated area has been recommended for future phases of works, the remedial action plan should only discuss theoretical receptor examples. The use of groundwater as a human drinking water supply has not been identified at any bores near the site. The cost benefit analysis of remedial options indicates that provision of alternative water supply is more cost effective than filtration, under all timeframes considered.
3. Summary of contamination and potential health risk

3.1 Contaminants of Interest

The Parsons Brinckerhoff Environmental Assessment report (PB 2012a) and subsequent assessment report (PB 2013b) confirmed that perfluorocarbon (PFC) chemicals were present in groundwater within Areas A2, B1, B2, B3, B4, B5, C1, C2, C3, F1 and off-site. The PFC chemicals originated as surfactant constituents of aqueous fire fighting foam (AFFF) that were stored and utilised at AACO. The extent of PFC impacts to groundwater has not been fully determined. It has been noted that two irrigation wells were utilised on-site for landscape irrigation and fire suppression, have been impacted by the PFCs in groundwater.

The previous assessment reports (PB 2012a, 2012b) also addressed soil sediment testing of drainage channels that identified low concentrations of PFCs in on-site soil. The concentrations were less than the adopted criteria for PFCs in soil and it was concluded that these concentrations did not warrant further soil assessment.

An annual groundwater monitoring event was conducted during December 2012 in order to assess temporal variability of contaminants (PB 2013b), as well as the assessment of on-site irrigation supply wells and the AACO pool. It was determined that groundwater was used to maintain water levels within the AACO pool on an as-needed basis. The assessment identified PFC impacts to the on-site irrigation bores (35453 and 35454) and the AACO swimming pool water (PB 2013b).

3.1.1 Primary contaminants of concern

PFCs are part of a larger family of perfluorinated alkyl acids (PFAAs) and their anions, all of which are anthropogenic pollutants. The primary PFC chemicals of concern which have been identified at the site include the following:

- Perfluorooctane sulfonate (PFOS).
- Perfluorooctanoic acid (PFOA).

PFOS is a persistent organic pollutant (POP), as defined by the Stockholm Convention in May 2009 under Annex B, Restricted Production and Use (UN 2009). The Stockholm Convention defines PFOS POP characteristics as follows:

PFOS is extremely persistent and has substantial bioaccumulating and biomagnifying properties, although it does not follow the classic pattern of other POPs by partitioning into fatty tissues but instead binds to proteins in the blood and the liver. It has a capacity to undergo long-range transport and also fulfills the toxicity criteria of the Stockholm Convention.
Other PFAAs, such as PFOA, are also believed to be not further degradable or metabolically converted to other compounds under ambient conditions (3M 1999a,b). Some of the additional compounds are known to be toxic and bioaccumulate in animals and humans (MDH 2008). Biodegradation of less-toxic long-chain (more than 8 carbons) fluorocarbons have been predicted to occur, but the final biotransformation metabolites would typically be PFOS or PFOA (Dimitrov et al 2004).

PFOS and to a lesser extent, PFOA, were key ingredients in AFFF that may have been stored by Defence in bulk and utilised beyond the 2002 production phase-out by 3M. PFOS-based AFFF was primarily produced in the US between the 1960s and 2003. After production phase-out in the US, PFOS and related compounds were primarily produced in China, and are still utilised throughout Asia. PFCs have not been produced in Australia. PFOS may also be utilised in aviation hydraulic fluid (considered an essential use). Hydraulic fluid releases to the environment have not been identified at the site, however there is a potential for release via waste oil USTs, such as the suspected leaky UST in Area C1.

3.1.2 Potential constituents of concern

The AFFFs containing PFOS and PFOA chemicals produced by electrochemical fluorination have been replaced by Defence with AFFF formulations that contain fluorotelomers produced by various types of telomerisation. However, it is likely that fluorotelomer products may contain PFOA as an impurity. It is also been observed that some long-chain fluorotelomers (greater than C6) may be metabolised into PFOA (Begley et al 2005).

One of the primary fluorotelomer compounds in AFFF is 6:2 fluorotelomer sulfonate (FtS), and it is considered to be a potential contaminant of concern. 6:2 FtS has only been detected in groundwater at low concentrations in a few monitoring wells at the site. Due to the lack of toxicological research and guideline concentrations, remediation options for 6:2 FtS were not considered to be a goal of this report. 6:2 FtS has been assessed in order to identify recent releases of fluorotelomer AFFF at the site.

3.2 PFC impacts

3.2.1 Potential and known sources

The two known or highly suspected source areas for PFOA or PFOS are the waste AFFF UST (tank C59) and waste oil UST (tank C60) located in Area C1. Tank C59 holds spent foam from the fire training pad (D20) and buildings C1 and C2. Numerous other areas within the site may also have been sources for PFCs in groundwater. These areas include: Area D2 fire training area (D20) and associated underground pipework connected to the Area C1 AFFF UST, AFFF underground drains in Area C1, AFFF waste collection UST (tank S12) in Area S1, AFFF waste collection UST (tank A83) in Area A2, former fire station (B4A), former fire training area (B9) in Area B3, former fuel farm in Area F1, and former Fire Pit of undetermined location. The former Fire Pit was reported to exist at the southern end of the aerodrome’s ‘western runoff’ (Bristow 1991). Based on early maps of the site provided by Defence, the former Fire Pit was located in Area North, approximately 200m north of the hot fuelling pads of Area A2 (Oakey Military Area Masterplan Appendices, undated).
3.2.2 Extent of impacts onsite and offsite

An Environmental Investigation undertaken by Parsons Brinckerhoff in 2012 (PB 2013b) indicated that there is widespread PFOS and PFOA impact in groundwater (Figure 3 and 4, Appendix A) with the highest concentration in Area B3. Area B3 formerly housed the AACO fire station and fire training area. High PFOS and PFOA impacts were also recorded in Area C3, Area C1 and Area S1. Both Areas C1 and S1 had/have an underground AFFF tank (UST and recovery tank) while Area C3 had USTs and TITs as potential sources of contamination.

The extent of PFC impacts to the upper alluvial aquifer above the adopted criteria appears to be delineated to the north and east of the site. Additional monitoring of on-site bores along the western and southern boundaries should be conducted.

The identified PFC impacts to the lower alluvial aquifer extend from the on-site areas of upper alluvial aquifer impacts to the west and southwest of the site. The extent of impact delineation within the lower alluvial aquifer is not complete. Additional groundwater impacts from PFCs have been identified on Commonwealth leased land where two irrigation bores (66256 and 83264) in the lower alluvial aquifer are seasonally operated. The two bores are used for agricultural production.

Four recently lower alluvial aquifer monitoring wells installed by Parsons Brinckerhoff confirmed concentrations of PFCs above the adopted investigation levels at three of 4 locations. While concentrations of PFCs at location MWA4-A were below the adopted criteria, the close proximity of PFCs in the monitoring well to a drinking water supply well (36603) warrants periodic monitoring. There is a significant potential for impacted groundwater to affect water quality at the Council water supply bore 36603.

3.3 Potential human health and ecological risks

As noted above, the Onsite and Offsite HHRAs for PFOS and PFOA in Groundwater (PB 2013c; 2013d) concluded that adverse health effects from exposure to PFOS and PFOA concentrations in groundwater to the populations of concern were unlikely. The Screening ERAs concluded that the likelihood of adverse effect to identified onsite and offsite ecological receptors, including the EPBC listed Murray Cod, is unable to be determined based on the existing information. Recommendations for higher level ERA are provided in (PB 2013c; 2013d).

It should be noted that the HHRAs (PB 2013c; 2013d) were based a number of assumptions regarding site conditions, human exposure and chemical toxicity. Even though site–specific parameters were included (eg. groundwater analytical and exposure assessment data), it was not possible to fully describe site conditions and human activities for the entire period of time considered in the HHRAs. The assumptions considered for the HHRAs were reasonably conservative in nature, to account for uncertainty in the parameter estimates and to protect public health by providing a deliberate margin of safety. The HHRA assessment approach did consider a fully probabilistic estimate of risk, but presented conditional estimates based on a number of assumptions regarding exposure and toxicity. Thus, it is necessary to specify the assumptions and uncertainties inherent in the risk assessment to place the risk estimates into perspective.
4. Site conceptual site model

PFCs are non-volatile, hydrophobic, lipophobic and miscible in water. These properties of PFCs are desirable in many industrial and consumer products, but they also lead to persistence in the environment. The unusual properties of PFCs are discussed in relation to the groundwater site conceptual model within this section.

4.1 Groundwater Flow Paths

The groundwater at the site is part of the Oakey Alluvial Aquifer system which consists of sandy clays that grade to sandy gravels with clay at a depth of approximately 19m below ground surface (BGS). The water table is typically 14.5m below ground level at the site. The upper alluvial aquifer typically exists from 14.5 mBGS to 19 mBGS at the site. In six locations a thin, discontinuous alluvial aquifer (perched aquifer) has been identified at depths varying from 3.3 mBGS to 12.3 mBGS. The discontinuous perched aquifer is a likely result of recent groundwater recharge or utility seepage where the vertical infiltration may be slowed by clay lenses or variably compacted fill material. The perched groundwater is considered separately from the upper alluvial aquifer, and is not considered to be a productive useable aquifer.

The lithology of the lower alluvial aquifer is not well understood due to limitations of drilling methods. It appears that there are discrete discontinuous zones of sand and gravel which are targeted by regional groundwater users. The sand and gravel zones are approximately an order of magnitude greater in hydraulic conductivity, than the upper alluvial aquifer zone (above 19 mBGS). The thickness of the alluvial aquifer increases in a downstream direction from Oakey, to as much as 40 mBGS. Based on observations of contaminants of concern, it is apparent that PFCs have migrated into the lower alluvial aquifer and been transported off-site.

Diagram 4.1 Conceptual hydrogeologic cross-section diagram

The regional groundwater flows westward towards the Condamine River and Oakey Creek. The vertical gradient is very small under natural conditions, but is expected to be highly negative (downward) between the upper and lower zones of the alluvial aquifer during periods of groundwater extraction.
4.2 Fate and transport

There are five general processes used to describe the fate and transport of contaminants in groundwater:

1. Advection – transport in groundwater flow.

PFCs appear to have little contaminant transport retardation (i.e. adsorption or degradation) based on the extent of the observed contaminant plume and properties of identified PFCs.

This is a likely result of the hydrophobic and lipophobic properties of PFC. These properties prevent PFCs from absorbing to most soil particles, with the exception of adsorption to some metal oxyhydroxides which are not known to be present at the site (Wang et al 2012).

Desorption is an important process to recognise where filtration with activated carbon is utilised. Given a wide range of PFCs that may be presented to an activated carbon filter media, short-chain fluorocarbons are known to desorb when ‘knocked-off’ the media by longer-chain fluorocarbons that have a stronger electrical affinity. Thus, immobilised PFCs can be remobilised as a filter media nears its saturation capacity.

Biodegradation of PFOS and PFOA has not been observed to occur. PFOA has been predicted to be a final degradation product for longer-chain hydrocarbons, if biodegradation actually occurs. Since biodegradation and adsorption is not known to occur in the aquifers and soils of the site, PFOS and PFOA are transported at nearly the same rate as groundwater.

As PFCs are being transported with the groundwater, the observed concentrations will decrease with distance due to the processes of diffusion and dispersion. The ultimate destination of the PFCs contaminant mass is further explored in the following discussion of groundwater extraction and discharge to surface water.

4.3 Groundwater extraction

There has been extensive development of water resources in the area since the 1950s to allow for agricultural irrigation and industrial and municipal water supplies. Industrial uses include on-site use of groundwater for landscape irrigation, fire protection and previously, swimming pool filling. Upon provision of a reticulated water supply system at the site and in the surrounding area, many of the registered bores previously used for domestic water supply (c.1943-1960) have been abandoned, but not decommissioned.
The volume of on-site irrigation water extracted from the two active irrigation bores is not known. It is expected that lawn and landscape irrigation has increased the dispersion of PFCs in the groundwater underlying the AACO over extended periods of time. Site visits during 2012 noted that the irrigation transfer pump for the airfield was rarely operable. This suggests that recirculating of groundwater impacts is limited to landscaped areas of the barracks, and near any leaking infrastructure (eg. irrigation lines and swimming pool).

The extent of groundwater use in the surrounding agricultural fields has not been quantified. Two irrigation bores located west of the internal airfield security fence are utilised for crop irrigation. According to the well operator, the bores are utilised continuously for approximately one month per year (January to February period). The water is utilised for crop irrigation that was observed to include corn and cotton, but is likely to change periodically.

During 1950 and 1971 the local council (now the Toowoomba Regional Council) installed municipal water supply bores on-site and within 1.5km of the site in the lower alluvial aquifer. The council bore (36603) located near the front gate house is known to be utilised during periods of drought to supplement the reticulated water supply system. The extracted water is pumped to the council’s reverse-osmosis treatment plant in Oakey, prior to public use.

### 4.4 Streams

Oakey Creek is deeply incised and is generally considered to be a losing stream that contributes surface water flow to the regional groundwater. Baseflow within the town of Oakey is primarily attributed to discharge of treated municipal effluent. The interaction of groundwater and surface water between the mouth of Oakey Creek and the town of Oakey is likely to act as a groundwater source and a discharge feature during different times of the year. It is unlikely that site contaminants will impact Oakey Creek in measureable quantities due to natural attenuation (ie. diffusion, dispersion and dilution) over 7.2 km between the site and the nearest probable discharge area downstream from Oakey. While it is noted that the creek is located 1.2 km south of the site, groundwater has been observed flowing west along a much longer flow path.

Drainage channels on the north side of the airfield flow toward Doctors Creek. Doctors Creek is an intermittent stream that loses water to the alluvial aquifer when surface water is present. The creek is not incised and occasionally floods the surrounding fields and roads during wet periods. A large sump and stormwater detention pond is located to the north of the site to assist farmers in draining their fields after wet periods. It is likely that this detention pond may act as a seasonal source of groundwater recharge. However, the groundwater mound is unlikely to be noticed during water level monitoring at the site because of the substantial distance from site (over 1km north).
5. Remediation goals and strategy

The strategy for remediating PFCs onsite and offsite must meet or exceed the existing environmental regulatory framework at the site. The remediation objectives are defined within this section as clean-up goals based on national guidance documents, where available.

5.1 Regulatory Framework

The Department of Defence operates the site that is located on land owned by the Commonwealth of Australia. Therefore, the management of environmental impacts to the site’s soil and groundwater are not under state or local jurisdiction. The primary regulatory requirements are related to the Environmental Protection and Biodiversity Conservation Act 1999 (as amended).

Impacts to off-site properties, including off-site receptors, would be regulated under Queensland's Environmental Protection Act (1994) that is administered by the Department of Environment and Heritage Protection.

The Defence engaged a Technical Advisor to review the work performed by Parsons Brinckerhoff and other consultants.

5.2 Remediation objectives

5.2.1 Source area remediation

Several areas of the upper alluvial aquifer have been identified to contain high concentrations of PFOS and PFOA. Although these concentrations may be indicative of a source area no specific source areas for remediation have been observed, with the exception of the former Fire Pit. The former Fire Pit was remediated for hydrocarbon impacts during 1997. The material was spread on-site near the former Fire Pit, and may have contained PFCs. The exact location of this area is unknown.

Since no areas of the site have been identified with soil impacts of PFCs indicative of a source area, no remedial activities for source area remediation have been proposed. The elevated groundwater concentrations observed at the site are too diffuse to warrant extractive remedial methods.

5.2.2 Receptor risk management

Although no unacceptable risks to human health and the environment have been identified, further environmental assessment is recommended, which could lead to identification of new exposure pathways and receptors. In the absence of any specific receptor risk requiring mitigation at present, remediation methods for the protection of potential residential groundwater users have been developed. Should any off-site residential groundwater users be identified that have unacceptable risks (ie. human health or otherwise), this RAP may be implemented to manage the exposure risk.
Continued groundwater monitoring for PFCs is an integral part of monitoring PFC plume migration in groundwater. A plan for monitored natural attenuation (MNA) of PFCs in groundwater is proposed for the site. An MNA plan is necessary to identify risks to ecological receptors (eg. Oakey Creek) and potential groundwater users identified in future delineation works.

5.2.3 Clean-up goals

The general clean-up goals for PFCs are as follows:

- Mitigation of risk (human health or other risks) from water supply well impacts, despite the existing risk assessment reports not identifying unacceptable risks to end-users (eg. on-site irrigation bores, 66 Orr Road pool/irrigation bore).
- Management of potential risk to ecological receptors from irrigation bores and discharge to surface streams.

The specific remediation goal concentrations (point-of-use) for PFOS and PFOA in raw drinking water supplies will be the drinking water guidelines of 0.3 µg/L (MDH 2008).

5.2.4 Background concentrations

PFAAs have been identified in many drinking water systems in Australia and globally at total PFAAs concentrations typically less than 5ng/L. (Thompson et al 2011). It is noted that the background concentration of PFAAs in public water supplies is less than the typical NATA accredited laboratory limit or reporting for PFOS, at 20 ng/L. Since PFAAs are anthropogenic contaminants, any detection above the instrument detection level is considered to be above the natural background concentrations.

5.3 Remediation strategy

Technical, financial and logistical considerations were considered and compiled for each technology within the Remedial Options Feasibility Study (ROFS, PB 2013e). The definitions and relevance of each consideration are provided below:

- Technical considerations include the physical ability to remove contamination within a reasonable time frame. A reasonable time frame is considered to be 5 years, based on CRAT ranking preferences, and 30 years is considered allowable based on principles of intergenerational equity.
- Logistical considerations include access, equipment availability, waste disposal and facility operations requirements.
- Financial considerations include the capital costs of equipment, installation and commissioning, operations, maintenance and waste disposal.

A summary of the ROFS findings is provided in Section 5.3.1 and 5.3.2 for recommended soil and groundwater remediation strategies (also refer to Appendix B).
5.3.1 Strategy for mitigation of risk to water supply well receptors

At several water supply wells used for irrigation, PFOS and PFOA have been detected in previous investigations. In order to mitigate any perceived risks two strategies were reviewed in the ROFS report (PB 2013e): filtration and provision of alternative water supplies.

Filtration may be the only feasible option if a residential supply well is impacted and there is no option for connection to a reticulated water supply system. In this instance, an activated carbon filter is the most readily available, most reliable and readily serviced filtration method.

Provision of an alternative water supply is the most cost effective option, if it is technically feasible and the owner is amenable. The operating costs are lower than filtration at all measured time frames.

In situations where an agricultural irrigation bore is used periodically at high flow rates, filtration is not likely to be practical. In such instances where the landowner has sufficient property holdings outside the PFOS plume boundary, and where future groundwater extraction is unlikely to cause PFOS plume migration, a new water supply well and associated distribution piping may be considered. While the capital costs are more substantial than connection to a reticulated system, the option may be less expensive than filtration with ongoing monitoring.

5.3.2 Strategy for management of risk to ecological receptors

In order to management potential risk to ecological receptors from impacted groundwater, monitored natural attenuation and additional PFC plume delineation is recommended. Delineation of the lower alluvial aquifer to the west and southwest of the site is necessary to determine risks to other groundwater users and ecological receptors, such as Oakey Creek. The development of an assessment plan is beyond the scope of this RAP, however, a MNA plan is proposed for the ongoing management of risk. There is no suitable in-situ groundwater remediation technology currently available to address diffuse concentrations of PFCs in the local aquifer.
6. Remediation approach

Based upon the findings of Remedial Options Feasibility Study and current understanding of the environmental status, the potentially applicable remedial strategies for the site are detailed below. Any significant changes to the environmental status or PFC toxicology may require revision of the remedial approach.

6.1 Preliminaries

Prior to commencement of the remedial works at the site, all relevant regulatory, Defence and site approvals for the use of the chosen remediation technology need to be completed prior to commencement of the activity. These documents may include:

- Defence Environmental Clearance Certificate (ECC)
- Environmental Management Plan (EMP)
- Site Safety Management Plan (SSMP)
- Health, Environmental and Safety plan (HESP), outlined in Section 6.1.1; and,
- All off-site remediation waste transport and disposal requirements, as indicated in Section 6.2.2.

Off-site works under the direction of Defence will require some or all of the above documents, subject to guidance provided by the Defence project manager.

Communications with off-site third-parties (eg. land owners, local council) must be approved and coordinated by Defence. Additional permits, inspections and access agreements may be required depending on the nature of the remedial works.

6.1.1 Health and safety plan

A HESP will be prepared prior to performing on-site works associated with this RAP. The HESP will also address the health and safety of site users in defined work areas when considering site security, excavation safety, vibration, noise, odour and dust levels.

Work associated with the remediation of the Site will conform at a minimum, to the requirements of the Commonwealth Work Health and Safety Act 2011 and associated Regulations.

Typically the health and safety plan will address the following issues:

- Regulatory Requirements.
- Responsibilities.
- Hazard Identification and Control.
- Chemical Hazard Control including handling, mixing and application of chemical oxidant and oxygen release compounds.
- Sample and Chemical Handling Procedures.
- Personal Protective Equipment.
- Work Zones.
- Decontamination Procedures.
- Emergency Response Plans.
- Contingency Plans.
- Incident Reporting.

6.2 **Mitigation of risk to water supply well receptors**

On a cost-basis, the preferred remedial option for any water supply well user perceived to be at-risk is to provide an alternative water supply. Should alternative water supplies be technical infeasible or disagreeable to the owner or user, filtration may be a viable option.

6.2.1 **Alternative water supply considerations**

The provision of an alternative water supply may be considered for water supply bores that have been impacted by PFCs above the drinking water criteria, even if the water is not used for human consumption.

In situations where a residential irrigation bore may be impacted by PFCs and a reticulated water supply is available, a contractual arrangement may be arranged for the decommissioning of the bore and prorated payment of reticulated water supply based on estimated usage. The advantages of this option are numerous: no ongoing monitoring, no spent filtration disposal costs, no long-term access agreement or site visits. These works could be completed under direct Defence supervision with the use of a licensed plumber.

In situations where an agricultural irrigation bore is used periodically at high flow rates, filtration is not likely to be practical. In such instances where the landowner has sufficient property holdings outside the PFOS plume boundary, and where future groundwater extraction is unlikely to cause PFOS plume migration, a new water supply well and associated distribution piping may be considered. While the capital costs are more substantial than connection to a reticulated system, the option may be less expensive than filtration with ongoing monitoring. The advantages are less clear in the case of well replacement, primarily due to potential requirements for inclusion of the new bore in a MNA plan. Replacement of a water supply bore must be completed by a licensed well driller, and under the supervision of a qualified environmental consultant to ensure correct well placement and construction. Water supply wells must be designed and installed in accordance with applicable guidelines (NUDLC 2011). Impacted off-site water supply bores should be decommissioned in accordance with state and local requirements, in order to prevent future re-commissioning of the bores.
6.2.2 Point-of-use filtration

Filtration may be the only feasible option if a residential irrigation well is impacted and there is no option for connection to a reticulated water supply system. Three types of filtration technologies are commonly used for PFC filtration. They are summarised in Sections 6.2.2.1 through 6.2.2.3.

All filtration methods require waste management and periodic monitoring. Annual water supply system monitoring should be conducted prior to filter changes, and include PFOA, PFOS and 6:2 FtS for analysis at NATA accredited laboratories. A sample should be collected from sample ports located upstream and downstream of the filter media.

6.2.2.1 Activated carbon

Activated carbon is filter media created through the processing of carbonaceous material. The surface area of activated carbon is extremely high, which allows for more opportunities for contaminants to adsorb to the media. Activated carbon comes in two general varieties, powdered activated carbon and granular activated carbon. For drinking water filtration or PFCs, granular activated carbon (GAC) is preferred.

In order to filter groundwater, GAC is placed in sealed filter media containers and placed within the existing well plumbing system. Depending on the specific application, a housing or shed may be required to protect the filtration containers and associated pipework from the weather. A GAC based remediation system also requires adequate pressure to force the water through the filter media. Gravity-fed systems or jet-style well pumps would require a booster pump and electrical source for operation. While the system is simple to install for a licensed plumber, owner and occupier permission, as well as an access agreement should be conducted in advance. Filter media would be expected to be replaced annually, at a licensed disposal facility.

The capacity of a residential GAC system will depend on the specific application, but would be in the general range of 40kg to 80kg. A process diagram is provided in Diagram 6.1.
Recent research has suggested that ion-exchange resins may be more efficient at PFOS removal from low salinity water (Senevirathna et al 2010). However, GAC has been widely used in residential and public water supply PFC remediation systems in the United States. Further discussion of ion-exchange resins is provided in Section 6.2.2.3.

### 6.2.2.2 Reverse-osmosis membrane

Reverse-osmosis is more expensive and typically only used at large-volume industrial and municipal water supply systems. Reverse-osmosis is already used by Toowoomba Regional Council (TRC) for filtering the groundwater extracted in the Oakey region, including bore 36603. Bore 36603 is not currently in operation, but it is likely to have PFC impacts based on an adjacent Sentry well.

TRC’s purpose for reverse-osmosis filtration was to remove excess salt from the water supply, so the efficiency of PFOS removal has probably never been determined. It has been recommended by Parsons Brinckerhoff to notify TRC of potential PFC impacts at bore 36603, so that TRC may evaluate the effectiveness of their filter systems. Additionally, TRC should identify PFCs in their saline waste stream to consider management options, if necessary.

### 6.2.2.3 Ion-exchange resin

Ion-exchange media exists for PFOS removal, but unlikely to be available in Australia at a lower cost than GAC. On a cost and availability basis, ion exchange is not recommended for consideration in the remedial action plan.
Since ion-exchange polymer resins reportedly have a higher adsorption capacity for PFOS than GAC (Senevirathna et al 2010), cost and availability should be reviewed before initiating a large-scale filter system installation. The 2010 study recommended Amberlite® IRA-400 as the best filter material to eliminate PFOS at concentrations over 1µg/L (Senevirathna et al). Amberlite® IRA-400 is a laboratory-grade resin that may not be available in industrial quantities. Prior to implementing an ion-exchange filter system, bench-scale testing by a qualified environmental consultant and NATA accredited laboratory is required. The bench-scale testing is necessary to determine if the brackish groundwater and other PFCs will preferential adsorb to the ion-exchange resin and block the contaminants of concern.

6.3 Management of risk to ecological receptors

Monitored natural attenuation (MNA) refers to the process of periodic groundwater monitoring necessary to quantify a reduction in quantity or concentration over time. The reduction of contaminants is a result of naturally occurring physical, chemical and biological processes. The preliminary assessment of MNA was completed within the Remedial Options Feasibility Study (ROFS, 2013e) which considered relevant technical, regulatory, financial and risk issues. The key technical considerations for preliminary approval were focused on PFCs in groundwater.

The acceptance of MNA as a long-term solution is dependent on further PFC delineation in groundwater and lack of suitable alternatives. The primary lines of evidence include continued monitoring for the PFC contaminants of concern to demonstrate attenuation over distance and time. There are no secondary lines or tertiary lines of evidence for natural attenuation, as the PFCs of concern do not further degrade.

6.3.1 Proposed monitoring well network

In order to build a fully adequate monitoring well network, it is necessary to have monitoring wells situated downgradient along the plume centre-line, source area and one un-impacted upgradient location (Beck and Mann 2010). A list of existing and proposed monitoring well network components is provided below:

- Hydraulically Upgradient Monitoring Wells:
  - MWE-B.

- Source Area Monitoring Wells:
  - Lower aquifer:
    - Irrigation well 35453 (Area B3)
    - Irrigation well 35454 (Area C3).
  - Upper aquifer:
    - MWB3-A
    - MWC1-D
- MWC1-E
- MWC1-F
- MWC1-G
- MWB5-C.

- **Hydraulically Downgradient Monitoring Wells:**
  - **Lower Aquifer:**
    - MWA1-D
    - MWA2-C
    - MWA4-B
    - Irrigation well 66256
    - Irrigation well 83264
    - Irrigation well 35983
    - 42231307
    - New wells to delineate downgradient PFC extent.
  - **Upper Aquifer:**
    - MWA1-A
    - MWA1-B
    - MWA1-C
    - MWA2-A
    - MWA2-B
    - MWB5-A
    - MWC2-O
    - MWC2-B.

- **Sentry Wells:**
  - MWA4-A to identify risks to Council bore 36603
  - Dis-used supply well 87138 to identify risks to a livestock bore approximately 50m south of 87138.

New monitoring wells should be installed in accordance with the *Minimum Construction Requirements for Water Bores in Australia* (NUDLC 2011).
6.3.2 MNA groundwater monitoring plan

A proposed MNA plan has been developed to observe seasonal variations and ensure long term monitoring until the remediation goals are met and there is no longer risk to any potential receptors. As there has not been specific investigation into PFCs in Australia the plan takes into account principals published by CRC Care (Beck and Mann 2010) for natural attenuation of hydrocarbon petroleum as well as Defence Contamination Directive (DCD) 5. As DCD 5 requires more frequent sampling for the first three years after a well has been installed, quarterly sampling rates have been adopted for the first three years of MNA. It is noted that quarterly groundwater monitoring was not previously conducted at any of the site’s monitor wells.

As indicated in DCD 5, all laboratory analysis must be conducted in accordance with Australian Standard AS 5667.11 Water quality-Sampling. Part 11: Guidance on sampling of groundwaters. All laboratory analysis for primary and secondary lines of evidence must be conducted in accordance with the National Environmental Protection Measures and National Association of Testing Authorities (NATA).

A proposed groundwater sampling plan is provided below:

- MNA Year 1 to 3:
  - Groundwater and PSH gauging: Quarterly, accessible bores listed in Section 6.3.1. Water supply bores are not accessible for gauging. PSH gauging only in Areas C1 and C2.
  - Sampling frequency: Quarterly, all bores listed in Section 6.3.1.
  - Quarterly analytes: constituents of concern and natural attenuation parameters.
  - Annual analytes: tertiary lines of evidence.

- MNA Year 4 onwards:
  - Groundwater and PSH gauging: Annual, accessible bores listed in Section 6.3.1. Water supply bores are not accessible for gauging. PSH gauging only in Areas C1 and C2.
  - Sampling frequency: Annual, all bores listed in Section 6.3.1.
  - Analytes: constituents of concern and natural attenuation parameters.

The proposed list of analytes for the MNA program is provided below:

- Constituents of concern:
  - Perfluorooctanesulfonic acid (PFOS)
  - Perfluorooctanoic acid (PFOA)
  - 6:2 FtS.
Natural attenuation parameters (secondary lines of evidence that could be beneficial for point-of-use remediation concerns):

- pH (field parameter)
- Oxidation-reduction potential (field parameter)
- Electrical conductivity (field parameter).

Tertiary lines of evidence:
- None.

A sufficient number of quality control samples must be collected during each sampling event to meet the data quality objectives of the MNA program. A summary of the data quality indicators (DQI) procedures is discussed in Table 6.1.

**Table 6.1 Data quality indicators**

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laboratory accreditation</td>
<td>All the laboratories engaged are accredited by National Association of Testing Authorities (NATA) for the analyses to be undertaken. The laboratories also perform their own internal QA/QC programs and will use appropriate detection limits for the analyses to be undertaken.</td>
</tr>
<tr>
<td>Field duplicates</td>
<td>Blind and split duplicates will be sampled at the rate of 1 in 10 primary samples for intra-laboratory and 1 in 20 primary samples for inter-laboratory. Relative percentage difference (RPD) will be calculated for the duplicate samples and compared to likely values (30 -50%) (AS 4482.1-2005).</td>
</tr>
<tr>
<td>Rinsate</td>
<td>One equipment rinsate will be collected per day of sampling and analysed for contaminants of concern. The results should have no detections of contaminants of concern.</td>
</tr>
</tbody>
</table>
| Laboratory quality control procedures | The laboratory QA/QC programs will be reviewed upon receiving the analytical results. The following items will be verified:  
  - Control samples: 80 – 120% recovery for waters  
  - Duplicate samples: <4 practical quantitation limit (PQL), +/- 2 PQL, 4-10 PQL, 0 – 25 or 50% RPD; >10 PQL – 0 10 or 30% RPD.  
  - Method blanks: 0 to <PQL |
7. Contingency management

In the event that proposed remediation measures indicate that the site remediation objectives or data quality objectives have not been achieved, contingency measures are to be reviewed and enacted when appropriate. Contingency measures for each remedial activity are provided within this section.

7.1 Risk to water supply well receptors

Contingency plans for anticipated problems that may arise from PFCs in water supplies after implementation of a point-of-use water filter system or replacement water bore are presented in Table 7.1 below.

<table>
<thead>
<tr>
<th>Remediation</th>
<th>Option</th>
<th>Scenario</th>
<th>Remedial Contingencies/Actions Required</th>
</tr>
</thead>
<tbody>
<tr>
<td>Filtration</td>
<td>Activated carbon or ion-exchange</td>
<td>Process is unable to reduced PFC content to required concentration for drinking and/or agricultural use.</td>
<td>Unlikely: Notify under what circumstances (eg. only agricultural use) the groundwater can be utilised. Change frequency of filter media replenishment. Add on a polishing filter media to remove low-level concentrations.</td>
</tr>
<tr>
<td>Filtration</td>
<td>Reverse-osmosis</td>
<td>Ineffective at reducing/removing PFCs</td>
<td>Unlikely: Significant dilution from other water supply well network wells expected. Decommission bore 36603. Install filter media at location 36603.</td>
</tr>
<tr>
<td>Provision of alternative water supply</td>
<td>Connection to reticulated systems</td>
<td>Waste stream contains unacceptable concentrations of PFC</td>
<td>Possible: Concentrated PFCs may be too high for waste stream. Decommission bore 36603. Install filter media at location 36603.</td>
</tr>
<tr>
<td>Provision of alternative water supply</td>
<td>Connection to reticulated systems</td>
<td>Refusal by owner</td>
<td>Possible: Proceed with filtration.</td>
</tr>
<tr>
<td>Provision of alternative water supply</td>
<td>Connection to reticulated systems</td>
<td>Irrigation demand too high</td>
<td>Likely: Consider replacement of bore.</td>
</tr>
<tr>
<td>Remediation Option</td>
<td>Scenario</td>
<td>Remedial Contingencies/Actions Required</td>
<td></td>
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<tr>
<td></td>
<td>PFC plume covers the entire property owned, or too close to PFC plume.</td>
<td>Possible: Proceed with connection to reticulated systems, Filtration, or Request ongoing monitoring and notify of risks, and Conduct eco-risk assessment for agricultural crops of concern.</td>
<td></td>
</tr>
</tbody>
</table>

The selection of filtration with activated carbon or provision of alternative water supplies in a connection to reticulated systems depends on the end-use, volume extracted and land ownership. Onsite groundwater is used mostly for fire water storage and non-food garden irrigation; therefore bore replacement may be the most cost effective option. An AACO replacement bore may be able to be installed at the far northeast boundary where there are no known impacts of PFC. However, a groundwater investigation should be conducted to confirm the PFC concentration in that portion of the site.

In the unlikely event that activated carbon filtration does not reduce the level of PFCs in extracted groundwater to appropriate levels, then a polishing filter may be required.
7.2 Risk to ecological receptors

Contingency plans for anticipated problems that may arise from PFCs impacting ecological receptors are presented in Table 7.2 below.

Table 7.2 Contingencies for PFCs impacts to ecological receptors

<table>
<thead>
<tr>
<th>Remediation</th>
<th>Option</th>
<th>Scenario</th>
<th>Remedial Contingencies/Actions Required</th>
</tr>
</thead>
<tbody>
<tr>
<td>MNA</td>
<td></td>
<td>Impacts to an ecological receptor</td>
<td>Possible: Conduct a Tier 2 Ecological Risk Assessment, and Continue with MNA Consider management options, such as restricted resource use (e.g. prohibition of eating fish).</td>
</tr>
</tbody>
</table>

Impacts to ecological receptors may require a Tier 2 Ecological risk Assessment and potential restrictions on resource use or other exposure management controls.
8. References


- Parsons Brinckerhoff 2013a, Human Health Risk Assessment, Petroleum Hydrocarbons in Areas C1 and C2 – Stage 3 Risk Assessment and Remediation Design, Army Aviation Centre Oakey, March 2013, draft.


- Parsons Brinckerhoff 2013c, Onsite Risk Assessment, PFOS and PFOA in Groundwater: Stage 3 Risk Assessment and Remediation Design, Army Aviation Centre Oakey, March 2013 draft.

- Parsons Brinckerhoff 2013d, Offsite Risk Assessment, PFOS and PFOA in Groundwater: Stage 3 Risk Assessment and Remediation Design, Army Aviation Centre Oakey, March 2013 draft.
- Parsons Brinckerhoff 2013e, Stage 3 Risk Assessment and Remediation Design at Army Aviation Centre Oakey Remediation Options Feasibility Study, May 2013.


- URS 2010. Stage 1 and Stage 2 Environmental Investigation at Army Aviation Centre, Oakey, Queensland, 14 October 2010.

9. Limitations

This assessment was restricted to the agreed-upon Scope of Services. No representations or warranties are made concerning the nature or quality of the soil and water, or any other substance on the Property, other than the visual observations and analytical data as stated in this report.

On all sites varying degrees of non-uniformity of the vertical and horizontal soil or groundwater conditions are encountered. Hence no sampling technique can completely eliminate the possibility that samples are not totally representative of soil and/or groundwater conditions encountered. The sampling can only reduce this possibility to an acceptable level.

It should also be recognised that site conditions, including contaminant extent and concentrations can change with time. This is particularly relevant if this report is used after a protracted delay, such that further investigation of the site may be necessary.

In preparing this report, Parsons Brinckerhoff has relied upon certain verbal information and documentation provided by the client and/or third parties. Except as discussed, Parsons Brinckerhoff did not attempt to independently verify the accuracy or completeness of that information, but did not detect any inconsistency or omission of a nature that might call into question the validity of any of it. To the extent that the conclusions in this report are based in whole or in part on such information, they are contingent on its validity. Parsons Brinckerhoff assume no responsibility for any consequences arising from any information or condition that was concealed, withheld, misrepresented, or otherwise not fully disclosed or available to Parsons Brinckerhoff.

Within the limitations of the agreed-upon Scope of Services, this assessment has been undertaken and performed in a professional manner, in accordance with generally accepted practices, using a degree of skill and care ordinarily exercised by reputable environmental consultants under similar circumstances. No other warranty, expressed or implied, is made.

This report is based upon the Scope of Services, and is subject to the Limitations defined herein. It has been prepared on behalf of Department of Defence for the benefit of Defence and subsequent tenderers of remedial options described within this report from Defence (‘the Nominated Reliants’). No person or organisation other than the Nominated Reliants is entitled to rely upon any part of the report without the prior written consent of Parsons Brinckerhoff. Any person other than a Nominated Reliant using or relying on this report shall have no legal recourse against Parsons Brinckerhoff or its parent or subsidiaries, and shall indemnify and defend them from and against all claims arising out of, or in conjunction with, such use or reliance.
Appendix A

Figures
Remediation Action Plan

Figure 4
Lower Alluvial Aquifer PFOA Contour Map - December 2012
Appendix B

Tables
<table>
<thead>
<tr>
<th>Remediation Technology</th>
<th>Advantages</th>
<th>Disadvantages</th>
<th>Applicable to fine grain matrix?</th>
<th>Applicable to PFOS and PFOA?</th>
<th>Time frame for cleanup</th>
<th>Technical Considerations</th>
<th>Logistical Considerations</th>
<th>Financial Considerations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excavation</td>
<td>100% removal, time frame</td>
<td>Accessibility, depth, limitations, cost, waste, disposal</td>
<td>Yes</td>
<td>Yes</td>
<td>very short</td>
<td>Technically prohibitive due to extent of plume.</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Monitored Natural Attenuation</td>
<td>No disruption, implementable, low carbon footprint</td>
<td>Time frame, containment</td>
<td>Yes</td>
<td>Yes</td>
<td>very long</td>
<td>Relies upon dilution.</td>
<td>No disruptions to site activities.</td>
<td>Ongoing monitoring, 4x per year in conjunction with other site environmental activities for groundwater impacts. Estimated cost of routine monitoring is under $50,000 per year.</td>
</tr>
<tr>
<td>In situ chemical oxidation (persulfate)</td>
<td>Time frame, source removal</td>
<td>Unproven in field trials, activation through heat or activator, by-products, cost, contact time with contaminant</td>
<td>No</td>
<td>Possible</td>
<td>very short to short</td>
<td>PFCs have been used in lab experiments only to oxidise PFOS and PFOA. Source area is diffuse, contact with contaminants too difficult. Technically prohibited.</td>
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<tr>
<td>Groundwater extraction and treatment</td>
<td>Proven</td>
<td>Time frame, ROI, high yield from lower alluvial aquifer</td>
<td>Yes</td>
<td>Yes</td>
<td>very long</td>
<td>Extraction of groundwater would provide hydraulic control, however the volume of water requiring extraction for control would be very large.</td>
<td>Minor site disruptions if a boundary control system was installed, however, waste management of concentrated PFCs may be expensive.</td>
<td>Cost prohibitive due to the large number of bores required to prevent off-site PFC migration and treatment costs. Estimated cost would be over $1,000,000.</td>
</tr>
<tr>
<td>In-situ soil heating</td>
<td>Time frame, source removal, proven, implementable</td>
<td>Hydraulic control required, by-products, cost, vapour generation, access</td>
<td>Yes</td>
<td>No</td>
<td>short</td>
<td>Technically prohibitive due to insufficient temperatures for PFC destruction (up to 700C, where 1,100C required).</td>
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<td>Proven, readily implemented</td>
<td>Spent carbon disposal containing concentrated PFCs.</td>
<td>Yes</td>
<td>very short</td>
<td>Established as method to protect municipal water supplies impacted by PFCs in the US.</td>
<td>No disruption to end user, except to change filters</td>
<td>Site visits for routine water testing and filter changes.</td>
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<tr>
<td>Reverse-Osmosis Filtration</td>
<td>Proven, readily implemented</td>
<td>Cost, brine waste disposal containing concentrated PFCs.</td>
<td>Yes</td>
<td>very short</td>
<td>Efficiency of PFC removal not known.</td>
<td>No disruption to end user, except to change filters</td>
<td>Site visits for routine water testing and filter changes.</td>
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<td>Ion Exchange Filtration</td>
<td>Proven, readily implemented</td>
<td>Spent media disposal containing concentrated PFCs.</td>
<td>Yes</td>
<td>very short</td>
<td>Efficiency of PFC removal not known. Unproven for large-scale water treatment.</td>
<td>Media not readily available in Australia.</td>
<td>Cost is greater than GAC for filtration.</td>
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<td>MatCARE Filtration</td>
<td>Australian designed</td>
<td>Unproven for water supply filtration. Created for wastewater filtration. Spent filter disposal.</td>
<td>Yes</td>
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<td>Efficiency of PFC removal not known. Filter flow-rates not published.</td>
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<td>100% removal, no breakthrough concerns</td>
<td>Legal agreement with well owner required, supply for agricultural wells probably not possible.</td>
<td>Yes</td>
<td>short</td>
<td>Contract negotiation for payment of water utility costs for a set period of time (eg. 30 years)</td>
<td>Requires legal support and administration be Defence. No future site visits or sampling.</td>
<td>Cost of setup and contract terms, estimated at under $50,000 per location.</td>
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<td>Legal agreement with well owner required, extensive pipe-run required to new location, suitable for agricultural wells.</td>
<td>Yes</td>
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<td>Requires legal support. No future site visits or sampling after hand-over.</td>
<td>Cost of well installation and pipe-runs. Estimated cost between 25,000 and 50,000, depending on the plumbing costs. No ongoing costs.</td>
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