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RNZAF Base Woodbourne PFAS Investigation: Comprehensive Site Investigation Report

New Zealand Defence Force

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RNZAF Base Woodbourne PFAS Investigation: Comprehensive Site Investigation Report

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New Zealand Defence Force

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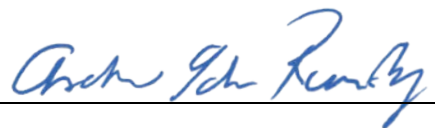
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Executive Summary

Environmental investigations at RNZAF Base Woodbourne have identified per- and poly-fluoroalkyl substances (PFAS) in soil and water on-site, and in water in the surrounding environment and neighbouring properties. PFAS was also found in animal tissue of terrestrial and aquatic biota downgradient of the site. The sampling investigations completed between December 2017 and September 2018 included several rounds of sampling both on-site and off-site. The sample media included groundwater, surface water, soil, sediment pore water, trade waste (liquid and solid), aqueous film forming foam and terrestrial and aquatic animal tissue. During the investigations:

- ∴ PFAS was detected at least once in all media sampled. Perfluorooctane sulfonate (PFOS) and perfluorohexane sulfonate (PFHxS) were the most prevalent compounds;
- ∴ PFAS was detected in groundwater across an area extending approximately seven kilometres east of Woodbourne. PFAS was detected in surface water up to six kilometres east of Woodbourne;
- ∴ The total PFAS groundwater plume, where concentrations exceed the laboratory limit of reporting (LOR) is estimated to cover an area of approximately 815 hectares. The area of the plume where concentrations exceed the guideline threshold (the sum of total perfluorooctane sulfonate and perfluorohexane sulfonate (PFOS + PFHxS) greater than 0.06 µg/L, adopted guideline value for drinking water when accounting for uncertainty of measurement) is approximately 200 hectares;
- ∴ Exceedances of applicable guidelines and trigger values were observed in groundwater, and fish tissue samples collected off-site;
- ∴ No PFAS were reported above the LOR in any groundwater samples collected from drinking water wells located at Base Woodbourne;
- ∴ Of the 203 private groundwater wells where samples were collected, seven wells had a concentration of PFOS + PFHxS greater than 0.06 µg/L, five of these wells were used for drinking at the time of the initial sampling. All households that previously took domestic water supply from these affected wells are currently supplied with an alternative drinking water supply;
- ∴ No PFAS were reported above the LOR in the groundwater samples collected from the Marlborough District Council (MDC) water supply wells for Blenheim for all of the PFAS analysed, except for a single sample for GW117. One groundwater sample had a concentration of PFHxS which was slightly above the LOR and did not exceed the drinking water guideline;

- ∴ The median concentrations of PFOS, PFHxS, PFOS + PFHxS and perfluorooctanoic acid (PFOA) were higher in groundwater samples collected on-site than the groundwater samples collected off-site. Of the groundwater and surface water samples collected off-site, higher concentrations of PFOS + PFHxS were observed at sample locations near Old Fairhall Creek. Lower concentrations of PFOS + PFHxS in groundwater were observed to the north near Old Renwick Road;
- ∴ Significantly higher PFOS + PFHxS concentrations were found in fish tissue samples collected from Old Fairhall Creek. Fish tissue samples collected from other locations downstream of Woodbourne had PFOS + PFHxS concentrations that were much lower than the samples collected from Old Fairhall Creek;
- ∴ The average PFOS concentration of all fish samples analysed from the Old Fairhall Creek was 201 µg/kg.
- ∴ Overall bioaccumulation has been observed in fish downstream of the base, however it is difficult to assess the ecological risks of PFAS bioaccumulation as there is insufficient information on the impacts of these substances within New Zealand ecosystems.
- ∴ The Ministry of Primary Industries (MPI) consumption advice is that children should not consume fish from Old Fairhall Creek and adult consumption should be limited to one serving per month. Currently there is no evidence that anyone is regularly consuming fish from this location and therefore this exposure pathway may be incomplete;
- ∴ On-site there is a significantly greater mass of PFAS (particularly PFOS) in the unsaturated soil¹ than in the groundwater; and,
- ∴ There is some evidence that transformation of other PFAS into measurable compounds (such as PFHxS) may be occurring. However, that evidence is inconclusive and other factors cannot be ruled out as contributing to the results observed.

A three-dimensional groundwater flow and transport model was developed to assist with estimating how the plume may evolve in the future. Modelling the plume behaviour has shown:

- ∴ That the plume is currently in a stable state;
- ∴ Some of the contaminated groundwater at shallow depths discharges from the groundwater system into the springs feeding both the Old Fairhall Creek and the Fairhall Co-op Drain. However, some contamination travels beyond the springs and into the confined aquifer beneath Blenheim, albeit with a reduced volume and at generally lower concentrations; and,

¹ Unsaturated soil refers to soil above the water table.

- ∴ The main receptors of PFAS contaminated groundwater are the spring-fed streams that form the headwaters of Old Fairhall Creek and Doctors Creek and any water supply bores within the plume area.

The following conclusions have been drawn following interpretation of the sample results and modelling of the groundwater plume:

- ∴ The on-site sampling results indicate that there is significantly greater mass of PFAS in the unsaturated soil than in the groundwater. The PFAS associated with the unsaturated zone acts as the source for the groundwater plume;
- ∴ The spring fed streams in the vicinity of Bells Road and Battys Road provide drainage to the groundwater that will limit the width of the main plume as it approaches the spring discharge area. The exit of plume mass into these spring-fed streams also constrains the eastwards groundwater plume migration.
- ∴ As a result, the behaviour and the spatial extent of the plume is likely to remain relatively constant for the foreseeable future (i.e. the next few decades), assuming that:
 - No additional PFAS sources are released into the soil on the site or into the groundwater plume;
 - No significant change in land use above the plume resulting in more people drinking PFAS contaminated water;
 - No significant change in groundwater abstraction which could potentially alter the direction of groundwater flow; and,
 - No substantial rises or falls in groundwater levels occur.

In order to cover a large investigation area in a short time frame, the groundwater sampling programme utilised existing groundwater abstraction wells. Well depths were not known for a number of these wells, although they are all expected to be less than 30 metres deep. The variability and uncertainty in the abstraction depths adds variability to the monitoring results and must be kept in mind when interpreting the sampling results, and conclusions that can be drawn from the data.

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1.0 Introduction

New Zealand Defence Force (NZDF) has been investigating the potential for contamination of soil, water and biota associated with the use and storage of products containing per- and poly-fluoroalkyl substances (PFAS) at the Royal New Zealand Air Force (RNZAF) Base Woodbourne (the 'site' or 'Woodbourne' or the 'base'). Investigations at Woodbourne have identified PFAS in soil and water on base, as well as in the surrounding environment and neighbouring properties.

Multiple PFAS investigations have been undertaken at Woodbourne, including a PFAS-specific Detailed Site Investigation (Aurecon, 2018) and an extensive external sampling investigation targeting groundwater, surface water, soil and animal tissue on private and public land downgradient of the base. The external sampling investigation consisting of four sampling rounds was completed by PDP in conjunction with several other environmental consultancies and was completed in late 2018 (PDP, 2018a; PDP, 2018b; PDP, 2018c; PDP, 2018d). A fifth sampling round was completed to assess the impact of PFAS on freshwater fish downgradient of the base in November 2018 (PDP, 2019a).

Pattle Delamore Partners Ltd (PDP) has been engaged by NZDF to prepare a comprehensive site investigation report (CSIR) documenting the PFAS investigations at Woodbourne.

1.1 Objectives and Scope

The key project objectives were to:

1. Collate and compare all on-site and off-site PFAS data collected across all media;
2. Provide a detailed plume assessment which describes:
 - a. The current extent of the plume in groundwater and surface water based on the sampling results;
 - b. The likely behaviour of the plume source;
 - c. Partitioning of the mass in different media (soil and groundwater);
 - d. The future extent of the plume; and
 - e. The extent that receptors might be adversely affected by the current and future behaviour of the plume in the short term;
3. Prepare an updated conceptual site model;
4. Conduct a tier 1 human health and ecological risk assessment (based on comparison of results with guidelines and the presence of a complete pathway); and,

5. Prepare a comprehensive site investigation report documenting the Woodbourne PFAS Investigation.

2.0 Background

2.1 Per- and Poly-fluoroalkyl Substances (PFAS)

PFAS are a large group of several thousand human-made per and poly-fluorinated compounds used for the manufacturing of a wide variety of products (ITRC, 2018a). Two major groups of PFAS (perfluoroalkyl substances and polyfluoroalkyl substances) are currently the focus of many PFAS investigations (refer to Diagram 1 for PFAS naming conventions). The basic structure of PFAS is a fluorinated chain of two or more carbon atoms with a charged functional group (the group of atoms which defines the way a molecule reacts) at one end. The strong carbon-fluorine bond means they are highly persistent in the environment and resist degradation (ITRC, 2018a).

Perfluoroalkyl acids (PFAAs) are fully fluorinated PFAS and are among the most commonly detected PFAS in the environment. PFAAs can enter the environment through the use of substances containing them or they can form due to the degradation of polyfluorinated precursors into perfluoroalkyl carboxylic acids (PFCAs) and perfluoroalkyl sulfonic acids (PFSAs). PFCAs such as perfluorooctanoic acid (PFOA) and PFSAs such as perfluorooctane sulfonate (PFOS) are terminal degradation products of select precursor polyfluoroalkyl substances (refer to Diagram 2 for PFAS degradation pathways).

Polyfluorinated PFAS substances on the other hand are partially fluorinated, therefore making them more susceptible to degradation. Fluorotelomers are polyfluoroalkyl substances produced by the telomerisation process. The degradation of fluorotelomer-based substances is a potential source of PFCAs in the environment (Buck *et al.*, 2011). 6:2 Fluorotelomer sulfonate (6:2 FTS) is known to break down into short chain PFCAs such as Perfluorohexanoic acid (PFHxA), Perfluoropentanoic acid (PFPeA) and Perfluorobutanoic acid (PFBA) via a series of intermediate compounds.

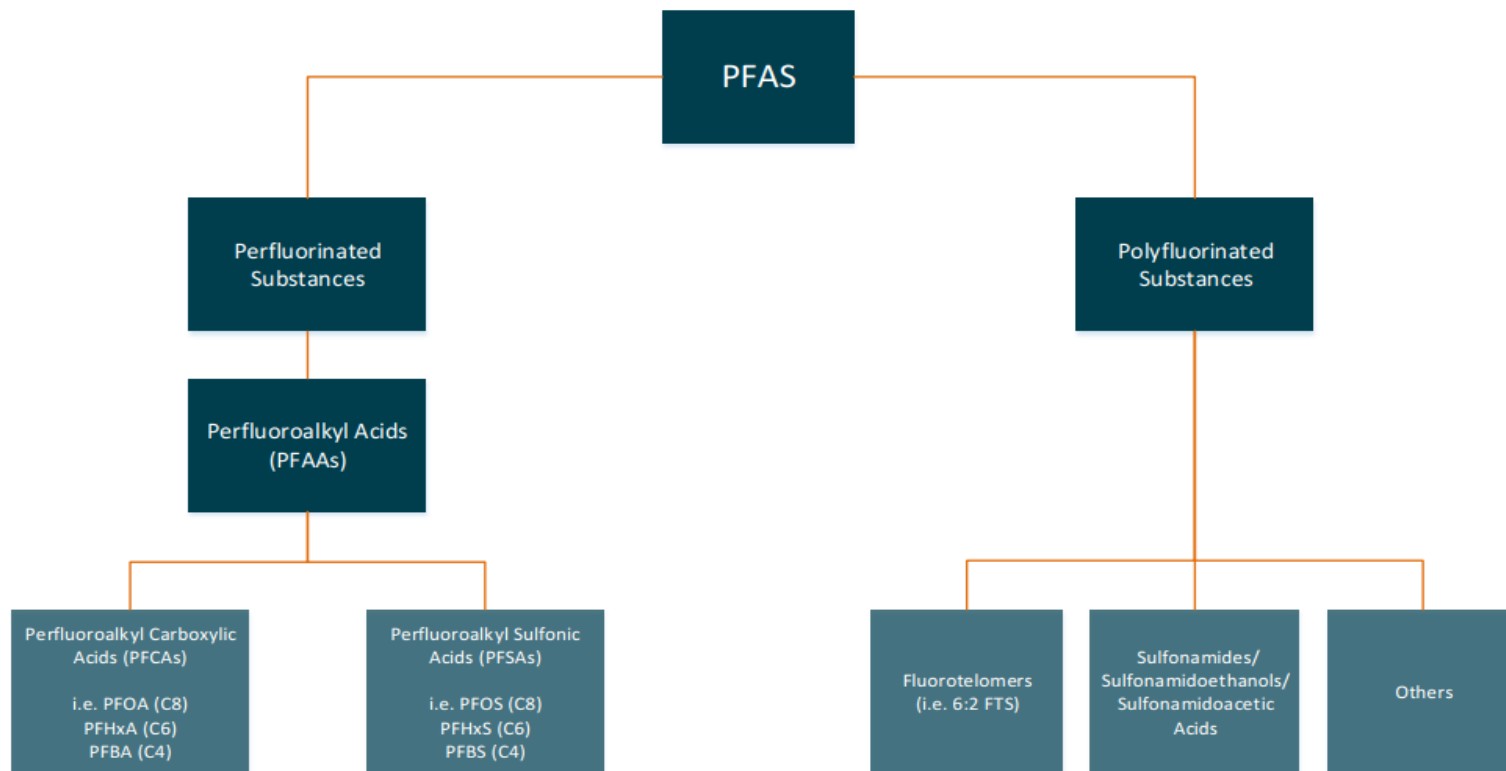


Diagram 1: PFAS Naming Conventions

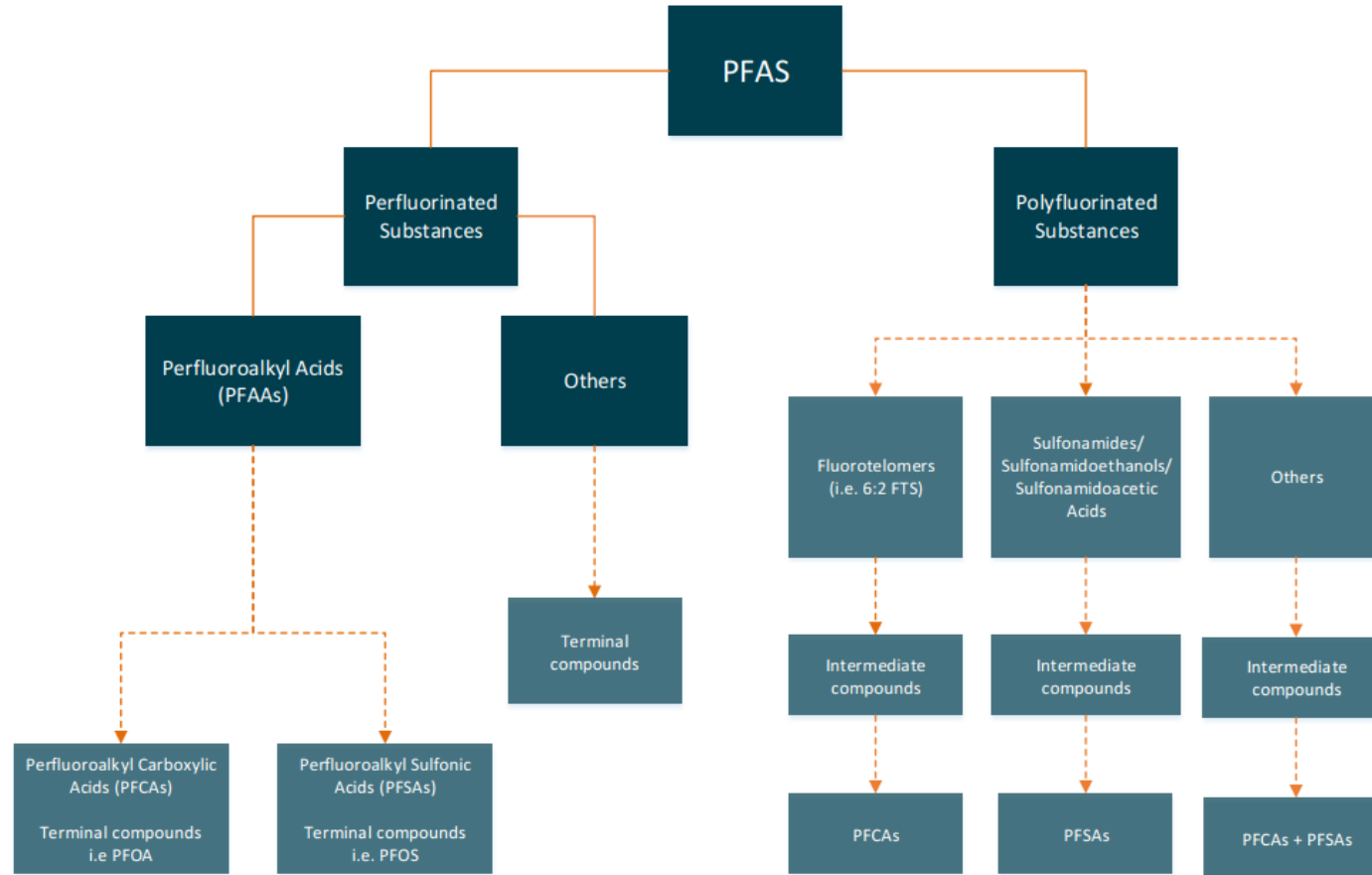


Diagram 2: PFAS Degradation and Transformation Pathways

Long chain² compounds can be more toxic than short chain compounds (particularly C8 compounds, however toxicity may decrease in very long chain compounds (i.e. C10 or greater). For PFCAs, carbon chains of eight carbon atoms or more (referred to as C8, e.g. PFOA) are considered a long chain. Long chain PFASs possess a carbon chain of six carbon atoms (referred to as C6 compounds) or more carbons (i.e. Perfluorohexane sulfonic acid, PFHxS (C6) and PFOS (C8) are both considered long chain sulfonic acids).

Whilst many PFAA precursors are monitored, numerous precursors are currently not measured due to a lack of available analytical standards.

2.2 PFAS in Aqueous Film Forming Foams

Some PFAS are major components of Aqueous Film Forming Foams (AFFF) which are used to extinguish fuel-based fires (ITRC, 2018a). AFFF was adopted worldwide in the 1970's and 1980's as a primary firefighting agent due to its ability to quickly suppress most hydrocarbon fuel fires (Place and Field, 2012). The formulations of these foams are proprietary and contain complex mixtures³ which vary year by year, by manufacturing process and with manufacturer (Baduel *et al.*, 2015, Anderson *et al.*, 2016). The principal PFAS in many modern foams are fluoroalkylthiamido sulfonates, fluoroalkylthiobetaine compounds and other related substances which are not reported as part of any current commercial analytical suites. Therefore, analysis of current foams may not accurately estimate the composition and concentrations of PFAS released historically.

Older AFFF developed between the 1960's and 2001 contained long chain 'C8' PFAS such as PFOS and PFOA (ITRC, 2018b). PFOS and PFOA are persistent (i.e. they do not degrade or only degrade very slowly in the environment), mobile and bioaccumulate in organisms (ITRC, 2018b). In the early 2000's, 3M voluntarily phased out the manufacture of PFOS. By 2006, eight major companies had also committed to reducing long chain compounds such as PFOA. In 2006, New Zealand prohibited the importing and manufacturing of firefighting foams containing PFOS or PFOA.

In 2009, the manufacture, import and use of PFOS was prohibited when the Annex B of the Stockholm Convention was amended to include PFOS. PFOA and PFHxS are currently candidate compounds for listing within the Stockholm convention.

In response to the phasing out of PFOS and PFOA containing AFFF, modern foams were developed containing fluorotelomer short chain (C6) PFAS which do not break down into long chain PFCAs such as PFOS. Shorter chain compounds are thought to be less bioaccumulative (Houtz *et al.*, 2016; ITRC, 2018b; Place &

² Chain length is the number of fluorinated carbons in a compound.

³ Baduel *et al* (2017) have found more than 60 different PFAS chemicals from 12 different fluorochemical classes at one firefighting training area.

Field, 2012). However, these newer foams can still contain precursors which can breakdown into PFOA (Anderson *et al.*, 2016).

2.3 Fate and Transport of PFAS from Fire Training Areas

Fire training areas (FTAs) are potential areas of highly concentrated PFAS from AFFF where hydrocarbon fires were repeatedly extinguished during training exercises for many decades. The fate and transport of PFAS released from AFFF is not well understood due to the uncertainty surrounding AFFF formulations and degradation pathways of PFAS. Lack of historic AFFF application records also makes it difficult to discern how PFAS plumes may develop over time.

The behaviour of PFAS in the environment is site specific and international studies may not be directly applicable to the site at Woodbourne, however some patterns can be observed, including:

- ∴ Some PFAS are highly soluble, making them very mobile in the environment, and in particular in groundwater and surface water;
- ∴ Some PFAS can sorb⁴ to solid surfaces; and,
- ∴ Some PFAS transform to terminal compounds. These terminal compounds (such as PFOS) are very persistent.

These attributes of PFAS are discussed further below.

2.3.1 Solubility

Water solubility of PFAS is dependent on the functional group. However, solubility tends to decrease with increasing molecular weight (the sum of the atomic weight values of the atoms in a molecule) and therefore generally decreases with the increasing length of the alkyl chain. Short chain PFAS molecules such as PFHxA, PFPeA and PFBA are therefore generally expected to preferentially partition to water and therefore, be more mobile (Scher *et al.*, 2018). PFOS and PFHxS which are long chain PFAS are moderately soluble and therefore are less mobile than short chain compounds.

2.3.2 Sorption

The ability of PFAS to sorb onto solid surfaces such as soil and sediment affects the mobility of PFAS and depends on the chain length (number of fluorinated carbons) and functional group. Additional factors influencing sorption include the pH of the soil, clay content and the presence of organic matter. Longer perfluorinated chain PFAS such as PFOS and PFHxS can moderately sorb to soil and sediment while shorter chain compounds (e.g. PFHxA (C6) and PFBA (C4)) are less strongly adsorbed onto solid phases and therefore are more highly mobile in the environment (Gellrich *et al.*, 2012).

⁴ The ability to adhere to a surface/other substances.

Numerous studies (e.g. Wang *et. al.*, 2011) have attempted to determine soil/water partition coefficients (K_d) for PFAS. The K_d value describes the preference for a compound to sorb to a solid (e.g. an aquifer matrix) or to remain in the liquid (e.g. groundwater). It is typically defined by the equation below:

$$K_d = \frac{Conc_{soil}}{Conc_{water}}$$

Where:

- ∴ $Conc_{soil}$ is the concentration of a PFAS in the soil;
- ∴ $Conc_{water}$ is the concentration of a PFAS in the water.

A K_d value of < 1 indicates the concentration in the water is greater than the concentration in the soil (i.e. the compound does not sorb strongly to the aquifer matrix). A K_d value of > 1 indicates the compound is more likely to sorb to the soil than to be present in the water.

The K_d values reported in the literature for some of the more commonly investigated PFAS are presented in Table 1, and show a wide range in values, highlighting the complexity in predicting the sorption behaviour of these chemicals. Furthermore, it appears laboratory derived distribution coefficients often underestimate the sorption of PFAS compared to values recorded in the field (e.g. Zareitalabad *et al.*, 2013). Field derived K_d values for PFOS and PFHxS at the Williamtown airbase, near Newcastle in New South Wales, were 1.19 L/kg and 0.11 L/kg respectively (AECOM, 2017).

Table 1: K_d Values of Common PFAS ^{1,2}	
Compound	K_d (pH 7)
PFOA	0 – 3.4
PFOS	0.1 – 97
PFHxS	0.6 – 3.2
<i>Note</i> 1. K_d values sourced from Wang <i>et. al.</i> (2011). 2. All units in L/kg.	

2.3.3 Persistence

PFOS and PFOA are persistent compounds which bioaccumulate in organisms (ITRC, 2018b). In 2009, the manufacture, import and use of PFOS was prohibited when the Annex B of the Stockholm Convention on Persistent Organic Pollutants was amended to include PFOS. Persistent organic pollutants are defined as synthetic, organic compounds that, to varying degrees, resist photolytic, biological, and chemical degradation (ITRC, 2017). PFAA compounds (such as PFOS) are thought to very persistent within the environment (ITRC, 2017).

2.3.4 Transport

Due to the mobility and persistence of PFAS in environment, PFAS can form large plumes depending on the hydrological and geological setting (ITRC, 2018b). Surface water and groundwater contamination from point source discharges of PFAS has been shown to extend for tens of kilometres (Awad *et al.*, 2011; Kwadijk *et al.*, 2014; AECOM, 2017; AECOM, 2018). The mobility of PFAS can be further influenced by the presence of other co-contaminants such as petroleum hydrocarbons (McKenzie *et al.*, 2016).

Despite the high mobility of PFAS, in the case of AFFF, a significant portion of the PFAS mass is thought to remain at the source where it is sorbed to soil in both the saturated and unsaturated zone. PFAS then slowly migrates down gradient with the flow of groundwater. Baduel *et al.*, (2015) estimated the source half-life⁵ of PFAS to be 25 years, indicating that a small amount of PFAS could continue to be a source for up to hundreds of years (Baduel *et al.*, 2015). It should be noted that Baduel *et al.* (2015) derived this value based on a kinetic model which used site specific soil leaching data and rainfall/runoff conditions which might be very different to those present at Woodbourne. However, there is no information on leaching half-lives in any of the other literature that PDP has reviewed. Most literature reviewed said that leaching of PFAS in soils can be a significant source of PFAS for several decades after the use of these compounds has ceased.

2.3.5 Transformation

Commercial laboratories typically analyse for between 25 – 35 individual PFAS, the remaining PFAS (estimated to be several hundred detected in the environment) , are generally not measured and are referred to in this report as ‘unquantified precursor compounds’. Measured and unquantified precursor PFAS can break down in storage or after they have been discharged into the environment (e.g. 6:2 FTS is a measured precursor compound which can breakdown into PFHxA and PFBA). Precursors are defined as a substance recognised as having the potential to transform into PFCAs or PFSA (Casson and Chiang, 2018). These precursor compounds can account for a large amount of unknown PFAS mass in the environment. Precursors have been found to account for 41 – 100% of total PFAS concentrations in newer AFFF formulations (i.e. those developed after PFOS was included in the Stockholm Convention) (Casson and Chiang, 2018). Although the PFAS that are measured by commercial laboratories represent only a small proportion of the total mass of PFAS they include all PFAS for which human health criteria or guidelines have been developed in Australasia.

⁵ Half-life is defined as the time taken for the concentrations of PFAS compounds at the source to halve.

2.3.6 Bioaccumulation

PFAS are known to accumulate in protein-rich tissues, such as blood plasma, muscle tissue and organs such as the liver. Long chain compounds such as PFOS and PFOA commonly bioaccumulate (PDP, 2018e). PFOS and to a lesser extent PFOA and PFHxS are the most commonly detected PFAS in biological and environmental samples, and as such most of the research into the biological uptake of PFAS has focussed on these compounds. In biota, PFOS is typically the most prevalent PFAS. PFOS is found to bioaccumulate in individual organisms and, biomagnify⁶ within organisms along the food chain (Giesy *et al.*, 2010; Houde *et al.*, 2006).

Multiple studies on bioaccumulation of PFAS in biota have shown long chain PFAS accumulate in higher concentrations in the liver and blood serum compared to muscle tissue (PDP, 2018e). The differences in potential bioaccumulation and depuration (elimination) rates are related to the physicochemical properties of PFAS such as carbon chain length, functional group and structure of the carbon chain, with branched⁷ isomers eliminated faster than linear isomers (e.g. Loveless *et al.*, 2006; Powley *et al.*, 2010). Depuration rates of PFAS in biota are known to vary between species, particularly between air breathing organisms in comparison to those such as fish that respire via gills or gill-like organs (PDP, 2017).

Exposure of terrestrial biota to PFAS may occur some distance downgradient of contaminated sites if impacted surface- or groundwater is used for either irrigation purposes or as animal drinking water (PDP, 2018e).

3.0 Site Description

3.1 Location

RNZAF Base Woodbourne is in the Marlborough Region in the upper South Island. Woodbourne is approximately 10 km west of Blenheim. Blenheim Regional Airport is located on-site and therefore the site includes military and civilian aircraft operations and associated facilities. The site includes a runway and airfield to the south, four aircraft hangars, the Blenheim Airport terminal building, and a variety of commercial buildings including Airbus. Accommodation blocks, NZDF housing and the site wastewater treatment plant are located north of the State Highway.

The site is surrounded by agricultural land, predominantly vineyards. The site is bordered by the Fairhall River to the south and west.

⁶ Accumulation of a substance in the organism at successively higher levels in a food chain.

⁷ Branched and linear isomers of the same compound have the same chemical formula however have a different structural arrangement of the atoms.

3.2 Geology – The Wairau Plain

The geology and hydrogeology for the Base Woodbourne and off-site investigation area are described by Davidson and Wilson (2011) as follows.

Woodbourne occurs on the Wairau Plain, which is an extensive deposit of unconsolidated sediments formed by glacial and river processes and derived primarily from the sediments of the Wairau River Valley, with smaller contributions from the valleys along the southern margin of the Wairau Plain, as shown by the arrows in Figure 1.

The deposited sediments are originally derived from the erosion of rock fragments from mountainous catchments, and therefore cover a wide range of particle sizes, from gravels down to sands, silts and clay sized particles.

The Wairau Plain has built up over deposits formed throughout the ice ages over the last several hundred thousand years, which comprised a successive sequence of colder glacial periods, separated by warmer interglacial periods. During the glacial periods, large volumes of gravel, sand, silt and clay were eroded from the Wairau River's mountainous catchment in the south-west and deposited as a poorly sorted mixture of grain sizes over the area by the alluvial processes of gravel bed rivers. During the interglacial periods, the contribution of new sediment to the plain was significantly less and many of the glacial deposits were reworked by the gravel bed river processes of the Wairau River and the Southern Valley rivers.

These gravel bed rivers are characterised by multiple, interlinking braided channels of flowing water within a broad active bed. River course changes over time periods of hundreds of thousands of years have built up the Wairau Plain, which contain gravelly strata extending to thicknesses of a few hundred meters.

As a result of these processes, the Wairau Plain is comprised of a complex mixture of gravels, sand, silt and clay originating from the higher catchment areas to the west and south of the Plain. These sediments are sorted to varying degrees ranging from poorly sorted mixtures of all grain sizes, through to better sorted deposits with gravels and coarse sand (with a lesser amount of finer sized particles) in some zones and fine sand, silt and clays in other zones.

3.2.1 Geological Units in the Vicinity of, and Downgradient of, Woodbourne

The upper 50 m of strata in the Woodbourne area comprises three geologic formations – the older Speargrass Formation, the overlying Early Rapaura Formation and the Late Rapaura Formation. A schematic geological cross-section showing the orientation of these three formations is presented in Figure 2.

The Speargrass Formation represents sediments that are of a lower permeability compared to the overlying, better sorted Rapaura Formation which have been

reworked by river processes and typically vary from around 0–20 m thick in the area east of Woodbourne.

The shallowest geological unit in the area is the recent gravel deposits associated with the present-day Southern Valley river channels.

3.3 Hydrogeology

With regard to groundwater flow, more rapid movement occurs through the more permeable coarser grained well-sorted zones of strata, whilst slower movement occurs through the sandy and silty zones.

Due to the nature of the river depositional processes these strata typically have a greater permeability in the direction of flowing water at the time of sediment deposition, with a lower permeability at right angles to the direction of deposition and the lowest permeability in the vertical direction.

These river-derived zones of strata are laid down in lenses parallel to the topography at the time of deposition (i.e. roughly horizontal). The lenses of finer grained sand and silt restrict the vertical permeability, but do not totally inhibit it, due to the lack of consistency and lateral continuity. This depositional behaviour encourages lateral groundwater flow through the strata, particularly in the direction in which the strata were deposited.

Due to the meandering pattern of many of these river processes, there can be variable orientations of the deposited strata on a small to medium scale (e.g. less than around 200 m). However, on a larger scale of a few hundred metres and more, the general direction of the highest permeability is expected to coincide with the direction of strata deposition.

3.3.1 Groundwater Flow

The rate and direction of groundwater flow through these gravel deposits is determined by the location and rate of inflow to the aquifer (recharge), the location and rate of discharge from the aquifer and the hydraulic conductivity (related to permeability) of the strata through which the groundwater flows between the recharge and discharge areas.

At the eastern (downgradient) end of the investigation area, the groundwater originates from seepage losses from surface waterways and infiltration of rainfall on the gravel plain. Sources of river seepage come from the Wairau River to the north and from the Southern Valley outflows from the Omaka River, Mill Stream, the Fairhall River, Golf Course Creek and Doctors Creek. Surface flows in these rivers readily infiltrate water to the aquifers and, for the southern valley streams, the length of flowing water in the surface channel varies depending on the amount of flow in the upper catchment and the groundwater level surrounding the river channel.

At a more localised scale, seasonal variations in groundwater flow direction will occur. Davidson and Wilson (2011) address seasonally varying groundwater flow directions entering the Woodbourne area. During wetter months, the groundwater flow direction reflects the contour of the land, i.e. southwest to northeast. During the summer months, the source of recharge to the Woodbourne area changes as the Southern Valley streams dry up and the main source of recharge changes from the southwest to the northwest and creates a more easterly groundwater flow direction.

A further influence on groundwater flow direction is the spring-fed streams that typically emerge east of Bells Road. These flow at rates of tens of L/s to 100s of L/s and act as drains, which draw groundwater towards them.

Consequently, the typical groundwater flow direction leaving RNZAF Base Woodbourne, as determined by groundwater elevations and the orientation of the strata, is expected to be in a general easterly direction with the potential for variations due to heterogeneity of the strata and the variable influences of streams, seasonal variations and pumping bores.

3.4 Hydrology

RNZAF Base Woodbourne is bordered by Mill Stream and Fairhall River to the south. Fairhall River continues to the northeast of the base and discharges into Ōpaoa River through the Fairhall Diversion. The reach adjacent to the base does not flow all year round.

There are multiple spring-fed streams located to the east of Woodbourne. Old Fairhall Creek and the Fairhall Co-op Drain are spring-fed streams that are located directly downgradient of the site. The Fairhall Co-op Drain joins with Doctors Creek which discharges into Taylor River. Old Fairhall Creek is located to the north of the Fairhall Co-op Drain and Doctors Creek and discharges into the Taylor River. The Taylor River runs through Blenheim and eventually discharges to the Ōpaoa River.

3.5 Ecology

Ecological assessments of the spring-fed streams on the Wairau Plain including Old Fairhall Creek, Fairhall Co-op Drain and Doctors Creek (Cawthron Institute, 2002) have identified a diverse range of macroinvertebrate taxa and shortfin eel (*Anguila australis*) populations in all three locations (Cawthron Institute, 2002). Longfin eel (*Anguila dieffenbachii*); and inanga (*Galaxias maculatus*) were also observed in Fairhall Co-op Drain and Doctors Creek, while common bully (*Gobiomorphus cotidianus*) was observed in Doctors Creek only.

The NIWA freshwater fish database (Crow, 2017) also identified longfin eel, shortfin eel and inanga in Doctor's Creek as well as common bully (*Gobiomorphus cotidianus*) and freshwater crayfish (*Paranephrops* spp.). The Fairhall Co-op Drain, and Old Fairhall Creek were not in the freshwater fish database.

The water quality index result for both Doctors Creek and Taylor River, measured for State of the Environment monitoring, was identified by MDC as marginal (MDC, 2016).

Multiple fish species were collected downstream of RNZAF Base Woodbourne as a part of the investigation into PFAS in freshwater fish tissue (PDP, 2019). Recreational fishing is popular in the wider Blenheim area, particularly trout fishing. Fish were collected from three sites downstream of the RNZAF Base Woodbourne and one control site upstream. The sample locations were as follows:

- ∴ Old Fairhall Creek;
- ∴ Taylor River;
- ∴ Ōpaoa River; and
- ∴ Omaka River (control site).

Multiple native fish species were caught at every site. These species included:

- ∴ Shortfin Eel (*Anguila australis*);
- ∴ Longfin Eel (*Anguila dieffenbachii*);
- ∴ Common Bully (*Gobiomorphus cotidianus*);
- ∴ Inanga (*Galaxias maculatus*); and
- ∴ Freshwater crayfish (*Paranephrops planifrons*).

Longfin eel, and common bully were caught at each site. Shortfin eel, and freshwater crayfish were caught at two locations. The most prevalent species in each catch was the longfin eel. Taylor River had a significantly larger catch of eels (shortfin and longfin) where over 150 eels were caught in three fyke nets. Eels of various sizes were found at the sites, including elvers at two sites. Freshwater crayfish were also found at the Taylor River and Omaka River sites. Due to environmental conditions, netting was the only fishing method used during the investigation and only one brown trout (*Salmo trutta*) was caught. The results of the investigation are summarised in Section 6 of this report. This sampling investigation did not target the Fairhall Co-op Drain or Doctors Creek.

4.0 AFFF Use at Woodbourne

AFFF has been used extensively over time at Woodbourne for firefighting and training purposes. AFFF has been stored for use in emergencies in static systems, fire service vehicles and smaller storage containers. Firefighting training exercises at Woodbourne have been carried out at multiple areas at the base on bare ground and concrete. The use of AFFF for firefighting and training can result in the contamination of soil and water through leaching and surface water

runoff. PFAS are known to leach from fire training pads over multiple decades (Baduel *et al.*, 2015).

Historically, NZDF used PFOS containing products such as 3M Light Water and Angus Alco Seal. NZDF have advised that foams such as 3M Light Water were used at NZDF sites between the years 1980 to 2002. Post 2002, and prohibition of PFOS containing foams, newer foams with fluorotelomers, such as Ansulite and Tridol S6, were likely to have been used.

A summary of the PFAS concentrations in AFFF recently sampled from Woodbourne is provided in Appendix A. These samples were collected to further understand the PFAS in the AFFF currently used on-site.

5.0 Methodology

5.1 Field Sampling

The on-site sampling of groundwater, trade waste (liquid and solid) surface water and soil was collected during a PFAS Specific DSI completed by Aurecon (2018). All methodologies for that sampling are detailed further in the DSI report (Aurecon, 2018).

Off-site sampling was undertaken by PDP in conjunction with other consultancies, of groundwater, surface water, sediment pore water, soil and animal tissue (chicken eggs) from multiple locations adjacent to RNZAF Base Woodbourne (PDP, 2018a; PDP, 2018b; PDP, 2018c; PDP, 2018d). The initial four sampling events were referred to as Stages A – D and were undertaken during the following dates:

- ∴ Stage A: 7 – 20 December 2017;
- ∴ Stage B: 13 – 28 February 2018;
- ∴ Stage C: 14 – 24 May 2018; and,
- ∴ Stage D: 10 – 14 September 2018.

In addition to this, monthly sampling of MDC groundwater bores and surface water sites was conducted and, in some cases, reported separately over the December 2017 to September 2018 sampling period. Animal tissue (freshwater fish and crustaceans), surface water and sediment pore water samples were collected and analysed for PFAS in a fifth sampling event (PDP, 2019). These samples were collected from 27 – 29 November 2018.

The sample locations were selected with the collaboration of NZDF and/or MDC. Due to the ubiquitous presence of PFAS in the environment, sampling of groundwater supply wells and surface water was undertaken following the methodology outlined in the *Sampling Protocols for Monitoring Per and Poly-fluorinated Compounds in Groundwater and Surface Water for New Zealand Defence Force* (PDP, 2018f) and the guidance documents referenced therein.

Sampling of animal tissue and sediment porewater was undertaken following procedures developed by PDP.

5.2 Guidelines

The relevant environmental and health-based guidelines for all media sampled on-site and off-site are summarised below. In New Zealand and Australia health-based guideline values have been developed for three PFAS only: PFOS, PFOA and PFHxS. These compounds are known to be associated with certain types of AFFF.

The health-based guideline values for PFOS + PFHxS, as well as PFOA, referenced in this report are derived using the Tolerable Daily Intake (TDI) for PFOS and PFOA established by Food Standards Australia New Zealand (FSANZ, 2017).

5.2.1 Water

Water guidelines and screening values are presented in Table 2 for drinking water, recreational water use and ecological protection.

5.2.1.1 Health-based Guidelines

The interim drinking water guidelines were developed by the Australian Government Department of Health (2017) and have been adopted by the New Zealand Ministry of Health (MoH). Off-site groundwater samples were compared to drinking water guidelines as applicable, based on water use information provided by the landowners and/or tenants. These guidelines are based on the following assumptions:

- ∴ Up to 90% of the TDI can be a result of non-drinking water sources (i.e. food consumption);
- ∴ The average weight of the person is 70 kg; and,
- ∴ An individual drinks 2 litres of water from the site per day for over a 70-year period (lifetime exposure).

Canadian drinking water screening values have been recently published (Government of Canada, 2019), for additional PFAS compounds not stated in the MOH drinking water guidelines. These screening values have not been adopted by New Zealand. Therefore, they have only been applied to compounds where there is no current New Zealand drinking water guideline. These screening values are shown in Table 3.

The recreational water quality guideline (AGNHMRC, 2019) is a health-based guidance value which indicates the amount of PFAS (specifically the sum of PFOS + PFHxS and PFOA) in water that a person can accidentally consume while in contact with water for recreational purposes. These guideline values assume that a person ingests 200 mL of PFAS contaminated water per day, 150 events per annum, over a lifetime.

The drinking water and recreational water quality guidelines assume that PFAS (PFOS + PFHxS and PFOA) exposure from the ingestion of water does not exceed 10 percent of the TDI for PFOS + PFHxS and PFOA.

5.2.1.2 Environmental Protection Guidelines

Surface water and sediment pore water sample results were compared to the ecosystem protection guidelines published in the PFAS National Environmental Management Plan (referred to as 'NEMP') (HEPA, 2018). These guidelines consisted of three ecosystem protection levels – 90%, 95% and 99% ecosystem protection. Surface water sample results have been compared to the draft ANZECC guidelines for the protection of 95% of species⁸. The guidelines have been derived using a species sensitive distribution using chronic toxicity data.

The ecosystem protection guidelines were not applied to the surface water samples during the first four external sampling campaigns (PDP, 2018a; PDP, 2018b; PDP, 2018c; PDP, 2018d) as these investigations were primarily focussed on human health.

⁸ Currently the draft ANZECC/ANZGWQG are under revision, which is likely to result in the 99% ecosystem protection value being increased significantly (Batley *et al.*, 2018). Therefore, the current draft 95% ecosystem protection value has been used in this assessment.

Table 2: Environmental and Human Health Guidelines - Water					
Guideline	Sum of Total PFOS + PFHxS	PFOA	Total PFHxS	Total PFOS	Source
Drinking Water	0.07 µg/L	0.56 µg/L	-	-	MoH ¹ , AGDoH ²
Recreational Water Quality	2 µg/L	10 µg/L	-	-	AGNHMRC ³
Ecological Freshwater Guideline – 99% ecosystem protection	-	19 µg/L	-	0.00023 µg/L	HEPA ⁴
Ecological Freshwater Guideline - 95% ecosystem protection ⁵	-	220 µg/L	-	0.13 µg/L	HEPA ⁴
Ecological Freshwater Guideline - 90% ecosystem protection ⁵	-	632 µg/L	-	2 µg/L	HEPA ⁴
<p>Notes:</p> <ol style="list-style-type: none"> 1. Ministry of Health (MoH, 2017) Interim Guidance Level for Drinking Water, PFOA, PFOS and PFHxS. 2. Australian Government Department of Health (AGDoH, 2017) Health Based Guidance Values for PFAS for Use in Site Investigations in Australia. 3. Australian Government National Health and Medical Research Council (AGNHMRC, 2019) Guidance on Per-fluoroalkyl and Poly-fluoroalkyl Substances (PFAS) in Recreational Water. 4. PFAS National Environmental Management Plan. Heads of EPAs Australia and New Zealand (HEPA), January 2018. 5. The 95% and 90% ecosystem protection level is not protective for bioaccumulation in organisms. 6. '-' denotes no guideline value. 					

Table 3: Canadian Drinking Water Screening Values ¹	
Analyte	Drinking Water Screening Value ²
PFBA	30
PFBS	15
PFPeA	0.2
PFHxA	0.2
PFHpA	0.2
PFNA	0.02
6:2 FTS	0.2
8:2 FTS	0.2
<p>Notes:</p> <ol style="list-style-type: none"> 1. All values in µg/L. 2. Values from Canadian Government (2019). Accessed 06.06.2019 from: https://www.canada.ca/en/services/health/publications/healthy-living/water-talk-drinking-water-screening-values-perfluoroalkylated-substances.html 	

5.2.2 Soil

Soil samples were compared to the guidelines produced in the PFAS NEMP (HEPA, 2018). These guideline values are used to assess the potential exposure from direct soil contact only and do not account for secondary exposure or bioaccumulation. The human health screening values were developed by assuming direct contact with PFAS impacted soil would not exceed 20 percent of the TDI. These values are shown in Table 4. Soil samples were collected on-site only so only the commercial/industrial guidelines are provided in Table 4.

The interim ecological direct exposure guideline is also included in Table 4, this value has been adopted from the human health criteria for public open space. The direct exposure guideline applies to organisms that live in soil or are closely associated with soil. The interim draft HEPA (2019) has updated the ecological guidelines for indirect exposure which is also included in Table 4. The indirect exposure guideline applies to the ways other types of organisms may be exposed such as through bioaccumulation.

Table 4: Environmental and Human Health Trigger Values – Soil					
Media	Sum of Total PFOS + PFHxS	PFOA	Total PFHxS	Total PFOS	Source
Soil (Industrial / commercial)	20,000 µg/kg	50,000 µg/kg	-	-	HEPA ^{1,2,3,4}
Interim soil – ecological direct exposure	-	10,000 µg/kg	-	1,000 µg/kg	HEPA ^{1,2,}
Interim soil – ecological indirect exposure	-	-	-	10 µg/kg	HEPA ²

Notes:

- PFAS National Environmental Management Plan. Heads of EPAs Australia and New Zealand (HEPA), January 2018.*
- PFAS National Environmental Management Plan Version 2 (DRAFT). Heads of EPAs Australia and New Zealand (HEPA), 2019.*
- Industrial/commercial, assumes 8 hrs spent indoors and 1 hr spent outdoors at a site such as a shop, office, factory or industrial site.*
- Where the guideline values refer to the sum of PFOS + PFHxS, this includes PFOS only, PFHxS only, and the sum of the two.*

5.2.3 Animal Tissue

Animal tissue such as chicken eggs, finfish flesh and crustaceans are compared to the Food Standards Australia New Zealand’s (FSANZ) trigger points (for further investigation); these values are provided in Table 5. The “trigger points” are the maximum concentration level of these chemicals that could be present in individual foods or food groups, so that even high consumers of these foods would not exceed the relevant TDI (FSANZ, 2017). For fish, the trigger points are based on consumption, by a child 2 – 6 years old, of 73 g per day, every day, of fish.

Table 5: Human Health Trigger Points for Investigation – Plant and Animal Tissue

Media	Sum of Total PFOS + PFHxS	PFOA	Source
Poultry eggs	11 µg/kg	85 µg/kg	FSANZ ¹
Finfish (all)	5.2 µg/kg	41 µg/kg	
Fish liver	280 µg/kg	2240 µg/kg	
Crustaceans - proposed trigger points for investigation ²	65 µg/kg	520 µg/kg	

Notes:

1. Assessment of potential dietary exposure to perfluorooctane sulfonate (PFOS), perfluorooctanoic acid (PFOA) and perfluorohexane sulfonate (PFHxS) occurring in foods sampled from contaminated sites – Table 8, Supporting Document 2. Food Standards Australia New Zealand (FSANZ), April 2017.
2. Occasionally consumed food, trigger points for investigation for crustaceans applied to molluscs due to small number of consumers of molluscs.

Fish muscle samples were also compared to the consumption guidelines for recreational catch freshwater finfish produced by the New Zealand Ministry for Primary Industries (MPI, 2018). These guidelines were developed to minimise the food safety risk associated with recreational catch of freshwater finfish. MPI state that, on average, adults consume freshwater fish less than twice a month (MPI, 2018). The guidelines are provided in Table 6 below.

MPI (2018) advise that the fish should be thoroughly gutted as PFAS is known to accumulate to high concentrations in fish livers.

Table 6: Consumption Guidelines for Recreational Catch Freshwater Finfish¹

Average PFOS concentration (µg/kg)	Child (2-10 years) (1 serving = 100g)	Adult (1 serving = 150g)
30-45	Limit of 3 servings/month	No advice necessary
45-60	Limit of 2 servings/month	
60-90	Limit of 1 serving/month	Limit of 3 servings/month
90-125	Limit of 1 serving/month	Limit of 2 servings/month
125-250	Do not consume	Limit of 1 serving/month
>250		Do not consume

Notes:

1. Ministry for Primary Industries. Accessed on 07/01/2019 from <http://www.mfe.govt.nz/sites/default/files/media/Land/marine-freshwater-fin-fish-PFOS-thresholds.pdf> on 07/01/2019.

5.2.4 Trade Waste

The New Zealand Environmental Protection Agency (NZ EPA) have recommended interim acceptance criteria for PFOS and PFOA discharges to trade waste (NZ EPA, 2019). The criteria provided are for PFOS and PFOA only as these are the restricted compounds under the HSNO Act. The recommended maximum concentration for both PFOS and PFOA in trade waste discharges is included in Table 7. A higher maximum concentration could be acceptable if a daily mass limit is set for PFOS and for PFOA. It is recommended that if daily limits are set for PFOS and/or PFOA, the maximum concentration for either of the two compounds should equal 1 µg/L. These recommended values are similar to the 95% ecosystem protection guideline in Table 2. The values in Table 7 should be considered as interim guidance values while the HEPA PFAS NEMP (2018) is in review. MDC have not yet adopted the EPA interim recommendations.

Table 7: Recommended Interim Trade Waste Acceptance Criteria		
Analyte	Interim Acceptance Criteria	Source
PFOS	0.1 µg/L	NZ EPA, 2019 ¹
PFOA	0.1 µg/L	
PFAS (total)	1 µg/L	
Notes: 1. <i>Disposal of PFAS Containing Wastewater to Trade Waste. Accessed on 20.06.2019 from: https://www.mfe.govt.nz/sites/default/files/media/Land/PFOS-disposal-to-trade-waste-guidance.pdf</i>		

A recommended PFOS limit of 0.3 mg/kg (dry weight) in biosolids is also provided by NZ EPA (2019). This value was compared to the trade waste sludge samples as there are no current trade waste sludge guidelines for PFAS in New Zealand.

6.0 Summary of Results

A summary of all sample results collected from both on-site and off-site are provided for all media below. The on-site and off-site sample locations are displayed in Figure 3, Figure 4, and Figure 5. The summary of results provided below primarily relate to the three PFAS (PFOS, PFHxS and PFOA) included in New Zealand adopted guidelines or screening/trigger values.

The median concentration reported in the tables below were calculated from the samples that were above the LOR. Where there were less than three samples above the LOR the median was not calculated.

Full results are tabulated and provided in Appendix B. These tables also include the geometric average for all samples above the LOR. For ease of reading, this information was not included in the summaries below.

6.1 Groundwater

Groundwater samples were collected from on-site and off-site locations between December 2017 and November 2018. A total of 637 groundwater samples were collected and analysed for PFAS from a combination of 27 on-site and 210 off-site locations. These results were compared to the interim drinking water guideline of 0.07 µg/L for the sum of PFOS + PFHxS and 0.56 µg/L for PFOA (AGDoH, 2017).

During the investigation primary samples were compared with duplicate samples both inter- and intra-lab, lab replicates and blanks to assess the uncertainty of measurement (UOM) (PDP 2018a, PDP 2018b, PDP 2018c, PDP 2018d).

An UOM of 10% was calculated. Because of the potential human health concerns with respect to drinking water, the UOM was applied to the results from all drinking water wells during the investigation. Therefore, all groundwater samples collected off-site were also compared to a concentration of 0.06 µg/L for the sum of PFOS + PFHxS to provide confidence that groundwater used for drinking water did not exceed the interim drinking water guideline.

6.1.1 On-site

A total of 100 groundwater (see Figure 3) samples were collected from the site and analysed for PFAS. These samples are summarised in Table 8. Of the 100 samples, one or more of the three PFAS of interest were reported above LOR in 68 (68%) samples. The on-site groundwater samples were not compared to the drinking water guideline as these wells are not currently used for drinking water. No samples from the on-site groundwater wells that are currently used for drinking water had PFAS concentrations above the LOR.

Table 8: Groundwater Sampling Results Summary – On-Site				
No. of Samples Analysed	Analyte	Concentration Range ¹	Median Concentration ²	No. of Samples >LOR
100	PFOS	<0.001 - 0.76	0.039	53
100	PFHxS	<0.001 - 1.9	0.028	67
100	Sum of PFOS + PFHxS	<0.001 - 2.4	0.054	68
100	PFOA	<0.001 - 0.13	0.01	46

Notes:

- All values in µg/L.
- Median concentration calculated using samples above LOR only.
- [www.health.gov.au/internet/main/publishing.nsf/content/A12B57E41EC9F326CA257BF0001F9E7D/\\$File/PFAS-interim-health-reference-values-june2016.pdf](http://www.health.gov.au/internet/main/publishing.nsf/content/A12B57E41EC9F326CA257BF0001F9E7D/$File/PFAS-interim-health-reference-values-june2016.pdf).

'NA' – Not applicable

6.1.2 Off-site

A total of 537 groundwater samples were collected from 210 off-site locations (Figure 4 and Figure 5). These samples are summarised in Table 9. Of the 537 samples, 252 (47%) samples had concentrations above the LOR for one or more PFAS. A total of five samples exceeded the interim drinking water guideline value (0.07 µg/L) for the sum of PFOS + PFHxS (HEPA, 2018; AGDoH, 2017). These samples were collected from three wells, two of which had exceeded the drinking water guideline twice (GW32 and GW56).

A total of 11 groundwater samples collected from seven wells had sum of PFOS + PFHxS concentrations that were greater than 0.06 µg/L and therefore may have exceeded the drinking water guideline when taking into account the UOM. This total is inclusive of the five groundwater samples mentioned above which exceeded the guideline value of 0.07 µg/L. Five of the wells were used for drinking water supply at the time of initial sampling.

Nine MDC water supply bores were sampled six times each between February 2018 and September 2018. One sample (GW117) during one monitoring round had a PFHxS concentration of 0.0014 µg/L, which was close to the LOR of 0.001 µg/L. No other PFAS from GW117 had concentrations above the LOR and none of the samples exceeded the drinking water guideline. No PFAS was reported above the LOR in any of the remaining samples collected from the MDC water supply wells.

The results for PFBA, PFBS, PFHxA, PFPeA, PFHpA, PFNA, 6:2 FTS and 8:2 FTS were compared to the Canadian Drinking Water Screening Values (Canadian Government, 2019) because these compounds are not included in the MoH or AGDoH guidelines. No off-site groundwater samples exceeded the relevant Canadian guidelines.

Table 9: Groundwater Sampling Results Summary – Off-Site					
No. of Samples Analysed	Analyte	Concentration Range ¹	Median Concentration ²	No. of Samples > LOR	Exceeds Guideline ^{3,4}
537	PFOS	<0.001 - 0.058	0.014	222	0
537	PFHxS	<0.001 - 0.074	0.019	235	1
537	Sum of PFOS + PFHxS	<0.001 - 0.11	0.032	252	5
537	PFOA	<0.001 - 0.0055	0.0023	161	0

Notes:

- All values in µg/L.
- Median concentration calculated using samples above LOR only.
- [www.health.gov.au/internet/main/publishing.nsf/content/A12B57E41EC9F326CA257BF0001F9E7D/\\$File/PFAS-interim-health-reference-values-june2016.pdf](http://www.health.gov.au/internet/main/publishing.nsf/content/A12B57E41EC9F326CA257BF0001F9E7D/$File/PFAS-interim-health-reference-values-june2016.pdf).
- Where the guideline values refer to the sum of PFOS + PFHxS, this includes PFOS only, PFHxS only, and the sum of the two.

'NA' – Not applicable

6.2 Surface Water

6.2.1 On-Site

There are no waterways in the RNZAF Base Woodbourne. A total of two stormwater samples were collected on-site and analysed for PFAS (refer to Figure 3 and Table 10). Sample WBN_EastCulvert_SW1 had concentrations of PFOA, PFPeA, PFHxA and PFHpA above LOR. Both stormwater samples had concentrations of PFHxA above the LOR.

Sample WBN_SouthCulvert_SW1 had concentrations of 6:2 FTS above the LOR. PFOS and PFHxS were not reported above the LOR in either sample. No stormwater samples exceeded the ANZECC 95% ecosystem protection guideline (HEPA, 2018).

Table 10: Surface Water Sampling Results Summary – On-Site					
No. of Samples Analysed	Analyte	Concentration Range ¹	Median Concentration ²	No. of Samples > LOR	Exceeds Guideline ³
2	PFOS	<0.001	NC	0	0
2	PFHxS	<0.001	NC	0	NA
2	Sum of PFOS + PFHxS	<0.001	NC	0	NA
2	PFOA	<0.001 – 0.0014	NC	1	0

Notes:

- All values in µg/L.
- Median concentration calculated using samples above LOR only.
- 95% ecosystem protection guideline: HEPA, 2018. PFAS National Environmental Management Plan. Heads of EPA Australia and New Zealand. January 2018.

'NC' – Not calculated
 'NA' – Not applicable

6.2.2 Off-Site

A total of 91 surface water samples were collected off-site and analysed for PFAS (refer to Table 11, Figure 4 and Figure 5). Of the 91 samples, 45 (49%) samples had concentrations above the LOR for one or more PFAS. No samples exceeded the draft ANZECC 95% ecosystem protection guideline (HEPA, 2018) or the recreational water health-based guideline value (AGNHMRC, 2019).

Table 11: Surface Water Sampling Results Summary – Off-Site					
No. of Samples Analysed	Analyte	Concentration Range ¹	Median Concentration ²	No. of Samples > LOR	Exceeds Guidelines ³
91	PFOS	<0.001 - 0.023	0.011	43	0
91	PFHxS	<0.001 - 0.039	0.019	45	NA
91	Sum of PFOS + PFHxS	<0.001 - 0.058	0.028	45	0
91	PFOA	<0.001 - 0.0035	0.0026	28	0

Notes:

- All values in µg/L.
- Median concentration calculated using samples above LOR only.
- 95% ecosystem protection guideline: HEPA, 2018. PFAS National Environmental Management Plan. Heads of EPA Australia and New Zealand. January 2018 and Australian Government National Health and Medical Research Council (AGNHMRC, 2019) Guidance on Per-fluoroalkyl and Poly-fluoroalkyl Substances (PFAS) in Recreational Water.

'NA' – Not applicable

6.3 Soil

6.3.1 On-Site

Soil samples were collected on base during the drilling works undertaken as part of the DSI (Aurecon, 2018). Fifteen soil samples were collected from seven boreholes (see Figure 3). Samples were collected from a range of depths (2.7 to 9.3 m bgl), most of which were in the unsaturated zone. PFAS was reported above the LOR in four samples (from three boreholes) which were all located in the unsaturated zone. Table 12 summarises the on-site soil results. No samples exceeded the HEPA (2018) health screening value for industrial/commercial areas. The soil samples collected on-site did not exceed the HEPA (2018) or the HEPA (2019) ecological guidelines for direct and indirect exposure.

Table 12: Soil Sampling Results Summary – On-Site					
No. of Samples Analysed	Analyte	Concentration Range ¹	Median Concentration ²	No. of Samples > LOR	Exceeds Guideline ³
15	PFOS	<0.001 - 0.0026	NC	2	NA
15	PFHxS	<0.001- 0.0015	NC	2	NA
15	Sum of PFOS + PFHxS	<0.001 - 0.0026	0.0015	4	0
15	PFOA	<0.001	NC	0	0

Notes:

- All values in mg/kg (dry weight).
- Median concentration calculated using samples above LOR only.
- Human health soil screening value – industrial / commercial: HEPA, 2018. PFAS National Environmental Management Plan. Heads of EPA Australia and New Zealand. January 2018.

'NC' – Not calculated

6.4 Sediment Pore Water

6.4.1 Off-Site

One sediment pore water sample was collected from the surface of the Old Fairhall Creek (Figure 5). This sample was collected to supplement the fish samples collected in the investigation carried out by PDP (2019a) to assess the potential for bioaccumulation of PFAS in freshwater biota. Due to the environmental conditions at the time of sampling, only one sediment pore water sample could be collected at one site only. Concentrations of PFOS, PFHxS and PFOA were all above the LOR in the sediment pore water sample collected from Old Fairhall Creek. However, concentrations did not exceed the ANZECC 95% ecosystem protection guideline (HEPA, 2018).

Table 13: Sediment Pore Water Sampling Results Summary – Off-Site

No. of Samples Analysed	Analyte	Concentration Range ¹	Median Concentration ²	No. of Samples > LOR	Exceeds Guideline ³
1	PFOS	0.0041	NC	1	0
1	PFHxS	0.032	NC	1	NA
1	Sum of PFOS + PFHxS	0.029	NC	1	0
1	PFOA	0.061	NC	1	0

Notes:

- All values in µg/L.
- Median concentration calculated using samples above LOR only.
- 95% ecosystem protection guideline: HEPA, 2018. PFAS National Environmental Management Plan. Heads of EPA Australia and New Zealand. January 2018.

'NA' – Not applicable

6.5 Chicken Eggs

A total of 12 chicken eggs were collected from properties adjacent to the site. These samples are summarised in the table below. Of the 12 samples, eight samples (75%) had concentrations above the LOR for one or more compound. PFOS was present in much higher concentrations in comparison to PFHxS. No samples exceeded the trigger point for further investigation (FSANZ, 2017). PFOA was not reported above the LOR in any samples.

Table 14: Chicken Egg Sampling Results Summary – Off-Site

No. of Samples Analysed	Analyte	Concentration Range ¹	Median Concentration ²	No. of Samples > LOR	Exceeds Trigger Value ³
12	PFOS	<0.25 - 6.5	1.4	8	0
12	PFHxS	<0.25 - 0.032	1.04	4	NA
12	Sum of PFOS + PFHxS	<0.25 - 9.7	1.55	8	0
12	PFOA	<0.25	NC	0	0

Notes:

- All values in µg/kg.
- Median concentration calculated using samples above LOR only.
- Proposed trigger points for investigation - Food Standards Australia New Zealand: [https://www.health.gov.au/internet/main/publishing.nsf/Content/2200FE086D480353CA2580C900817CDC/\\$File/Consolidated-report-perflourianted-chemicals-food.pdf](https://www.health.gov.au/internet/main/publishing.nsf/Content/2200FE086D480353CA2580C900817CDC/$File/Consolidated-report-perflourianted-chemicals-food.pdf)

'NA' – Not applicable

6.6 Freshwater Biota

6.6.1 Fish Flesh

Ten fish flesh (i.e. edible tissue) samples were analysed for PFAS (Figure 4 and Figure 5). A combination of species including longfin eel, shortfin eel, common bully, inanga and brown trout were collected from sites both upstream and downstream of the base. These samples are summarised in Table 15. Significantly elevated PFAS concentrations were observed in fish samples from Old Fairhall Creek, with a maximum sum of PFOS + PFHxS concentration of 340 µg/kg. The fish flesh samples collected from the remaining sites had much lower PFAS concentrations or did not have any PFAS reported. The median PFOS + PFHxS concentration of the fish flesh samples collected from Old Fairhall Creek and analysed for PFAS was 180 µg/kg. The fish flesh samples collected from the Taylor River had a median PFOS + PFHxS concentration of 16 µg/kg, which was the second highest median of the sites where fish flesh samples were collected.

The flesh from fish collected from Old Fairhall Creek were the only fish flesh samples with Total PFOS concentrations over 30 µg/kg, which is the action threshold in the consumption guidelines for recreational catch freshwater finfish (MPI, 2018). Based on the average calculation of PFOS concentrations in fish flesh from the Old Fairhall Creek; fish from this site should not be consumed by children, and adults should limit consumption to one serving per month (MPI, 2018). The consumption guideline is based on the average concentration observed in samples of fish flesh at a particular location.

Table 15: Fish Flesh Sampling Results Summary – Off-Site					
No. of Samples Analysed	Analyte	Concentration Range ¹	Median Concentration ²	No. of Samples > LOR	Exceeds Trigger Value ³
10	PFOS	<0.25 - 330	6.66	6	5
10	PFHxS	<0.25 – 7.2	0.13	4	NA
10	Sum of PFOS + PFHxS	<0.25 - 340	6.66	8	0
10	PFOA	<0.25 – 1.2	NC	2	0

Notes:

- All values in µg/kg.
- Median concentration calculated using samples above LOR only.
- Proposed trigger points for investigation - Food Standards Australia New Zealand: [https://www.health.gov.au/internet/main/publishing.nsf/Content/2200FE086D480353CA2580C900817CDC/\\$File/Consolidated-report-perflourianted-chemicals-food.pdf](https://www.health.gov.au/internet/main/publishing.nsf/Content/2200FE086D480353CA2580C900817CDC/$File/Consolidated-report-perflourianted-chemicals-food.pdf)

'NC' – Not calculated
 'NA' – Not applicable

6.6.2 Fish Liver

Two fish livers were also analysed for PFAS (refer to Table 16). A longfin eel from Old Fairhall Creek and a brown trout from the Taylor River had significantly higher PFAS concentrations in comparison to the fish flesh. These samples are summarised below. PFOS and PFHxS were present in high concentrations in both samples. The eel liver sample from Old Fairhall Creek had the highest sum of PFOS + PFHxS concentration of 640 µg/kg. This eel sample exceeded the trigger value (FSANZ, 2017) for fish livers for both the concentration of PFOS and the sum of PFOS + PFHxS. MPI (2018) states that the liver should be thoroughly removed from the fish prior to consumption. PFOA was above the LOR for the eel liver sample only.

Table 16: Fish Liver Sampling Results Summary – Off-Site				
No. of Samples Analysed	Analyte	Concentration Range ¹	No. of Samples > LOR	Exceeds Trigger Value ²
2	PFOS	140 - 610	2	1
2	PFHxS	1.2 – 28	2	NA
2	Sum of PFOS + PFHxS	140 - 640	2	1
2	PFOA	<1 – 3.4	1	0

Notes:

- All values in µg/kg.
- Proposed trigger points for investigation - Food Standards Australia New Zealand: [https://www.health.gov.au/internet/main/publishing.nsf/Content/2200FE086D480353CA2580C900817CDC/\\$File/Consolidated-report-perflourianted-chemicals-food.pdf](https://www.health.gov.au/internet/main/publishing.nsf/Content/2200FE086D480353CA2580C900817CDC/$File/Consolidated-report-perflourianted-chemicals-food.pdf)

'NA' – Not applicable

6.6.3 Fish Roe

Fish roe from the brown trout sample caught in the Taylor River was also analysed for PFAS. This sample is summarised in Table 17. PFOS and PFHxS were present in much higher concentrations in comparison to the flesh sample of the brown trout. The concentration of PFOS in the roe sample was 80 µg/kg, compared to 13 µg/kg in the flesh sample.

Table 17: Fish Roe Sampling Results Summary – Off-Site

No. of Samples Analysed	Analyte	Concentration ¹
1	PFOS	80
1	PFHxS	0.79
1	Sum of PFOS + PFHxS	81
1	PFOA	<0.25

Notes:
 1. All values in µg/kg.

6.6.4 Freshwater Crayfish

Two freshwater crayfish samples were collected; one from Taylor River and one from the Reference Site in the Omaka River. The sample collected from the Taylor River had a PFOS concentration of 1.1 µg/kg. Perfluorotetradecanoic Acid (PFTeDA) was the only other PFAS in the analytical suite that had concentrations above the LOR. No PFAS was reported above the LOR in the freshwater crayfish sample collected from the reference site at Omaka River.

6.7 Trade Waste

6.7.1 Trade Waste Wastewater

Three trade waste wastewater samples were collected on-site and analysed for PFAS (refer to Table 18). Two additional samples were collected from the stormwater system in locations where AFFF may be used and stormwater can be directed to trade waste in an emergency (identified as the ‘crash fire’ samples, Figure 3).

One trade waste sample (S1) and the two crash fire samples had PFOS concentrations that were above the LOR. The trade waste and crash fire samples had PFOS concentrations above the LOR which exceeded the interim recommended trade waste discharge limit (NZ EPA, 2019). PFOA and PFHxS were not reported above the LOR in any samples.

Table 18: Trade Waste Water Sampling Results Summary – Off-Site					
No. of Samples Analysed	Analyte	Concentration Range ¹	Median Concentration ^{1,2}	No. of Samples > LOR	Exceeds Guidance Limit ³
5	PFOS	<0.1 - 0.54	0.27	3	3
5	PFHxS	<0.1	NC	0	NA
5	Sum of PFOS + PFHxS	<0.1 – 0.54	0.27	3	NA
5	PFOA	<0.1	NC	0	0

Notes:

- All values in µg/L.
- Median concentration calculated using samples above LOR only. Where there were less than three samples above the LOR the median concentration was not calculated.
- Recommended trade waste discharge limits – NZ EPA, 2019 - Disposal of PFAS Containing Wastewater to Trade Waste. Accessed on 20.06.2019 from: <https://www.mfe.govt.nz/sites/default/files/media/Land/PFOS-disposal-to-trade-waste-guidance.pdf>.

'NC' – Not calculated
 'NA' – Not applicable

6.7.2 Trade Waste Sludge

Two trade waste sludge samples (see Figure 3) were collected on-site and analysed for PFAS. These samples are summarised in the Table 19. Concentrations for PFOS, PFHxS and PFOA were all above LOR. The highest concentration was for the sum of PFOS + PFHxS which was 0.15 mg/kg (dry weight). This was from the sample WBN_Tradewaste_S1, which had the highest concentration of the two samples for PFOS, PFHxS, Sum of PFOS + PFHxS and PFOA. As only two samples were collected the median concentration was not calculated. No sludge solids exceeded the biosolids acceptance criteria from the NZ EPA (2019).

Table 19: Trade Waste Sludge Sampling Results Summary – Off-Site				
No. of Samples Analysed	Analyte	Concentration Range ¹	No. of Samples > LOR	Exceeds Guidance Level ²
2	PFOS	0.057 – 0.15	2	0
2	PFHxS	0.0012 – 0.002	2	NA
2	Sum of PFOS + PFHxS	0.058 – 0.15	2	NA
2	PFOA	0.001 - 0.0022	2	NA

Notes:

- All values in mg/kg (dry weight).
- NZ EPA, 2019 - Disposal of PFAS Containing Wastewater to Trade Waste. Accessed on 20.06.2019 from: <https://www.mfe.govt.nz/sites/default/files/media/Land/PFOS-disposal-to-trade-waste-guidance.pdf>

'NA' – Not applicable

7.0 Discussion

7.1 Results Summary

All media sampled on-site and off-site had concentrations of one or more PFAS above the LOR.

7.1.1 Guideline Exceedances

For the samples collected on-site:

- ∴ The groundwater samples collected on-site were not compared to the drinking water guideline as most of the wells were not currently used for drinking water. PFAS was not reported above the LOR in any of the on-site wells that are currently used for drinking water;
- ∴ Of the two stormwater samples collected on-site, only one sample had concentrations of one or more PFAS above the LOR. No relevant guidelines were exceeded; and,
- ∴ No soil samples exceeded the health-based guidelines for industrial/commercial areas.

For the samples collected off-site:

- ∴ Five groundwater samples exceeded the drinking water guideline value of 0.07 µg/L for the sum of PFOS + PFHxS. Eleven groundwater samples had a sum of PFOS + PFHxS concentration higher than 0.06 µg/L and may have exceeded the drinking water guideline when taking into account the UOM;
- ∴ No surface water and/or sediment pore water samples exceeded the ANZECC 95% species protection guideline value;
- ∴ No chicken egg samples exceeded the FSANZ trigger point for further investigation;
- ∴ Five fish flesh samples exceeded the FSANZ trigger point for further investigation however the samples collected from Old Fairhall Creek were the only fish flesh samples to trigger consumption advice under the recreational catch freshwater finfish consumption guidelines (MPI, 2018); and,
- ∴ One fish liver sample exceeded the trigger point for further investigation. The consumption guidelines are not applicable to fish liver as MPI (2018) recommend that fish should be thoroughly gutted before consumption. This is because PFOS are known to accumulate to higher concentrations in the liver in comparison to other edible tissues.

7.2 Trends

7.2.1 Spatial Patterns

The highest concentrations of PFAS observed were from groundwater samples collected on-site. The median concentration of PFOS was higher in the samples collected on-site compared to off-site, however the median concentration of PFHxS was higher in the samples collected off-site. PFHxS can form due to the breakdown of other PFAS but is also a component of the legacy AFFF used by NZDF.

Of the groundwater samples collected off-site, higher concentrations of the sum of PFOS + PFHxS were observed from groundwater sample locations located at Bells Road, David Street and along Old Fairhall Creek. This results in a relatively narrow central PFAS plume extending eastwards to Blenheim (Figure 7). The sample results show relatively continuous detection of PFAS in groundwater north as far as Middle Renwick Rd and south as far as Fairhall Co-op Drain.

Of the off-site surface water samples, the median PFHxS concentration was higher than the median PFOS concentration. Like the groundwater samples, higher concentrations of PFOS + PFHxS were observed in surface water samples collected centrally within the plume, particularly from Old Fairhall Creek. PFAS was observed in other surface water samples collected from the Fairhall Co-op Drain and the Taylor River however at much lower concentrations in comparison to the surface water samples collected from the Old Fairhall Creek. This pattern is also reflective of PFAS concentrations in freshwater fish.

In addition to the central plume, a cluster of slightly elevated PFAS concentrations were also located in areas further north along Old Renwick Road, as shown in Figure 7. Most of the groundwater samples collected in this area did not exceed a PFOS + PFHxS concentration of 0.0089 µg/L; however, two groundwater wells had two or more samples with a magnitude higher PFOS + PFHxS concentration. This area could be downgradient of the main plume area at times when surface flow and groundwater flow out of the southern valleys is a more significant source of recharge to the area.

PFAS was also present above the LOR in groundwater samples near New Renwick Road to the south of the plume. Due to the position of these bores relative to the groundwater plume and the direction of groundwater flow the presence of PFAS in groundwater in this area must originate from a separate source.

7.2.2 Seasonal Changes

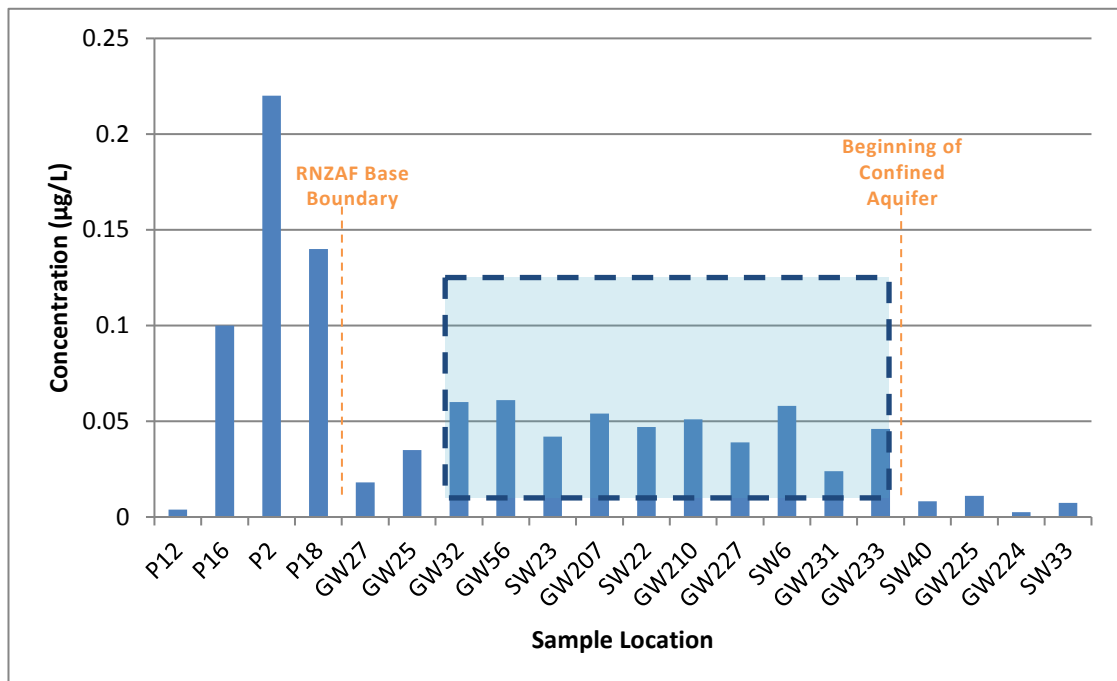
The short sampling period was not sufficient to assess seasonal trends, particularly in groundwater. Some fluctuations have been observed in samples collected over the seasons, however, no discernible seasonal patterns were found.

7.2.3 Groundwater Transects

Sample result data was analysed and compared along two groundwater transects that extended through areas of interest within the groundwater plume.

7.2.3.1 Groundwater Transect One – Sum of PFOS + PFHxS Concentration

The orientation of Transect 1 and associated samples are shown in Figure 6. The transect ran through the centre of the plume; extending north east at the eastern end, towards the MDC water supply bores. The concentrations of PFOS + PFHxS for groundwater and surface water samples along Transect 1 are graphed below. These on-site samples were collected in April 2018 and the off-site samples were collected May 2018. The results are in $\mu\text{g/L}$ and include surface water sample locations along the transect to understand the behaviour of the PFAS plume and groundwater/surface water interaction.



Graph 1: Sum of PFOS + PFHxS – Groundwater Transect 1

As previously mentioned, the concentration of PFOS + PFHxS is significantly higher in the on-site wells (except for P12 located at the western, upgradient, end of the plume). The concentration decreases off-site and the higher concentrations for the main areas of the off-site plume fluctuate between 0.039 and 0.061 $\mu\text{g/L}$. These variations will partly be due to the locations of the bore intakes (both laterally and at depth) relative to the centre line of the peak plume concentrations and the heterogeneity of the strata through which the groundwater moves. The concentration of PFOS + PFHxS is relatively stable

between Bells Road (GW56) and Battys Road (GW233). Further to the east of Purkiss Street it is expected that concentrations will be lower, and the occurrence of higher groundwater concentrations will become less common, due to the loss of groundwater flow (and plume mass) into the spring-fed streams that emerge to the east of Bells Road. Further east from bore GW233, the sampled groundwater bores were most likely to be located within the confined section of the aquifer which is separated from the surface water streams by low permeability sediments. Surface water samples in the Old Fairhall Creek had higher concentrations of PFOS + PFHxS compared to samples northeast of the Taylor River. The Taylor River is influenced by dilution from other surface water flows from areas outside of the plume area. The water sample collected from Old Fairhall Creek (SW6) had the highest PFOS + PFHxS concentration which represented shallow groundwater emerging into the spring-fed stream.

7.2.3.2 Groundwater Transect Two – Sum of PFOS + PFHxS Concentration

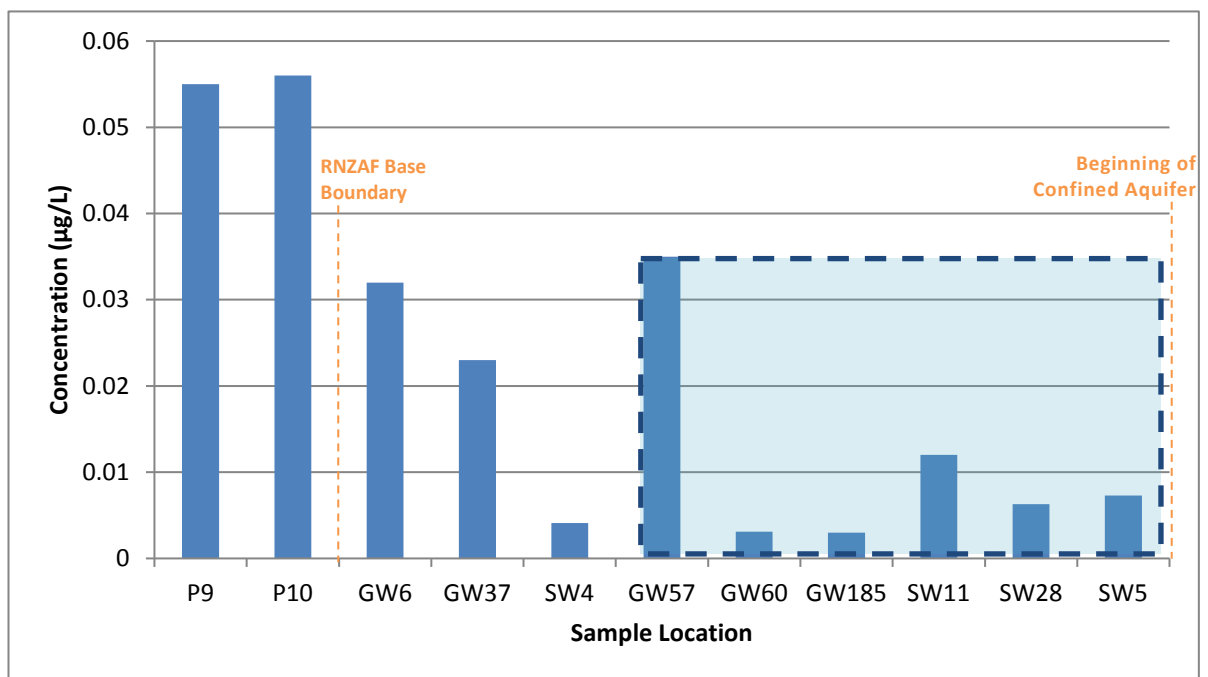
The orientation of Transect 2 is shown on Figure 6. The transect started at the historical Woodbourne fire pit location near the south eastern boundary of the site and extends along the southern section of the plume. The concentrations of PFOS + PFHxS for groundwater and surface water samples along Transect 2 are presented in the graph below. The sample collected along Transect 2 with the highest PFOS + PFHxS concentration was collected on-site from MW2B, which was located near the historical fire pit FTA. The concentration of PFOS + PFHxS in the water sample collected from MW2B was 0.93 µg/L which is an order of magnitude higher than the remaining samples collected along Transect 2. For this reason, MW2B was not included in Graph 2 below. As the PFOS + PFHxS concentrations in groundwater samples along Transect 2 were much lower than the sample sites on Transect 1, the Y-axis scale on Graph 2 is an order of magnitude lower than Graph 1.

On-site groundwater samples collected from P9 and P10 had similar concentrations of PFOS + PFHxS which were higher than concentrations in the off-site samples collected along Transect 2. The water samples collected from the off-site locations fluctuated along the transect, due to the different sampling points location and depths relative to the plume distribution.

Sample GW57 has been included in the transect as it had the highest PFOS + PFHxS concentration directly adjacent to the Fairhall Co-op Drain, however this may not be representative as only one sample was collected at this location (during Stage 1 of the investigation). GW57 was collected from a pipe draining shallow groundwater which flows into the Fairhall Co-op Drain. The remaining samples were collected from April – May 2018 and are assumed to have been collected in similar environmental conditions (i.e. water levels, base flow etc.). This shallow groundwater is north of the Fairhall Co-op Drain which is a more concentrated section of the plume. The Fairhall Co-op drain receives water from this section of the water table however it is diluted by deeper groundwater from

both the north and south which explains why the surface water samples have a lower concentration. This dilution paired with the distance from the centre of the plume results in lower surface water concentrations in the Fairhall Co-op Drain and Doctors Creek in comparison to the Old Fairhall Creek. GW6 and GW37 were located more centrally within the plume.

The remaining groundwater samples collected from groundwater wells directly adjacent to the Fairhall Co-op Drain had lower concentrations of PFOS + PFHxS in comparison to the surface water samples collected from the Fairhall Co-op Drain and Doctor’s Creek. This observation is consistent with the surface water at these locations reflecting the shallowest groundwater with higher PFAS concentrations, whereas the bores sampled along the Fairhall Co-op Drain and Doctors Creek are likely from intakes positioned several metres below the water table and therefore have lower concentrations of PFAS.



Graph 2: Sum of PFOS + PFHxS – Groundwater Transect 2

7.3 Evidence for Transformation of PFAS

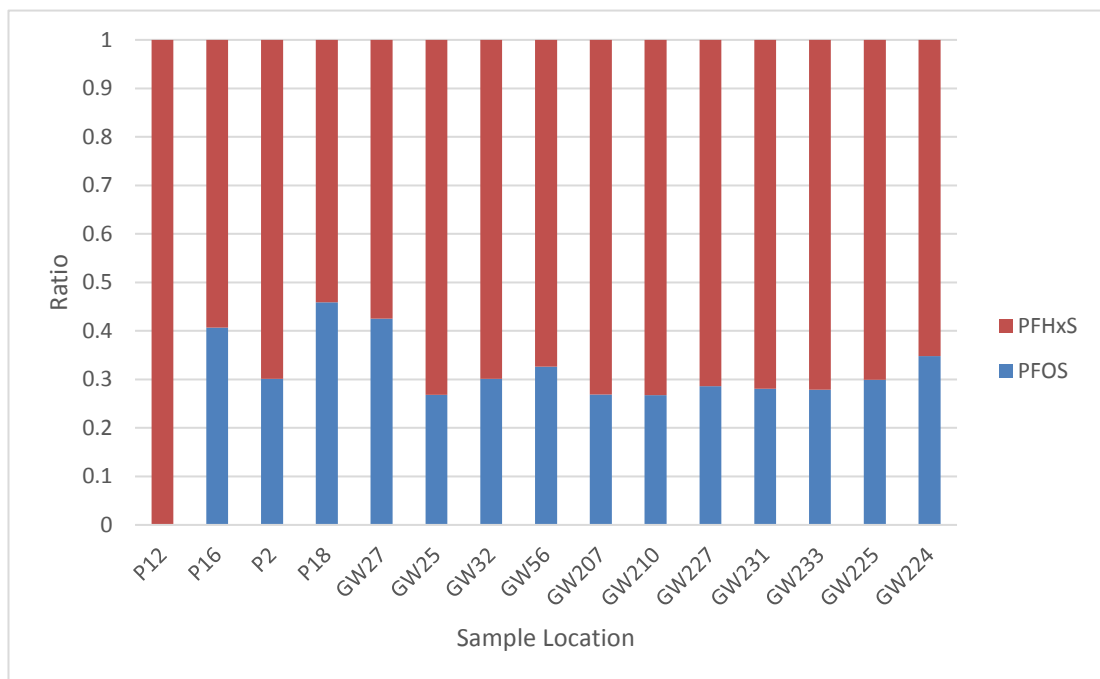
The data along Transect 1 (Figure 6) was assessed to look for evidence of transformation of PFAS.

Unquantifiable precursor compounds contained within AFFF foams can break down into short chain PFCA and potentially PFHxS, PFOS and PFOA. To identify if these transformations were occurring; PDP (PDP, 2019b) analysed the groundwater along Transect 1 to see if:

- ∴ Short chain PFAA compounds (the ultimate decay products of PFAS precursor compounds) were present in the plume;
- ∴ Precursor compounds (i.e. fluorotelomers) decreased with distance from Base Woodbourne;
- ∴ The relative ratio of short chain PFAA to PFOS changed. The breakdown of precursor compounds could lead to a relative increase of short chain PFAA compared to PFOS; and,
- ∴ The relative ratio of PFHxS to PFOS changed. Again, some C6 precursors compounds found in modern foams could breakdown to form PFHxS.

The following potential evidence for transformation of PFAS was identified:

- ∴ The ratio of PFHxS to PFOS was slightly higher in the off-site samples when compared with the on-site samples which might indicate transformation of some unquantified precursor PFAS into PFHxS. However, this ratio was relatively stable throughout the off-site samples as illustrated in Graph 3.
- ∴ 6:2FTS concentrations, which were lower off-site than those detected on-site.
- ∴ Short chain precursors compounds were detected within the plume.



Graph 3: Ratio of PFOS vs PFHxS

However, all these observations could be attributed to other factors such as dilution, changes in formulation over time and/or presence of short chain compounds in the original formulations.

Overall, there is some inconclusive evidence that transformation is occurring, however other factors cannot be ruled out as contributing to the results observed. Currently there is no systematic evidence that transformation of PFAS precursors will result in an increase risk to off-site receptors.

7.4 PFAS Mass Estimate

7.4.1 Soils and Unsaturated Zone

To estimate the mass of PFAS in the unsaturated soil versus the mass in the underlying groundwater water on-site, the ratio of PFAS in soil versus groundwater was calculated for the three boreholes where PFAS was found in soil, these three boreholes are listed below (Figure 3):

- ∴ Monitoring well P10 – soil sample from 3.7 m bgl;
- ∴ Monitoring well P13 – soil sample from 7.5 m bgl; and,
- ∴ Monitoring well P17 – soil sample from 5.5 m bgl.

The ratio was calculated by dividing the concentration of PFOS and PFHxS in soil samples (in $\mu\text{g}/\text{kg}$) by the corresponding concentration of PFOS and PFHxS in groundwater (in $\mu\text{g}/\text{L}$)⁹. Where possible, groundwater samples collected at approximately the same time as the soil samples were used for the comparison. A ratio was only calculated for samples where both PFOS and PFHxS concentrations were above the LOR.

The results presented in Table 20 show a wide range in ratios, however these results are consistent with the wide range of K_d values presented in Table 1, reflecting the complexity of sorption behaviour of PFAS. The relative amount of PFOS in the soil is higher than the relative amount of PFHxS, which is consistent with PFOS having generally higher K_d values in comparison to PFHxS. At P10, located at the historic fire pit, the amount of PFOS mass in the soil is approximately 100 times that present in the groundwater. At P17, located at the former trade waste treatment facility, the amount of PFOS mass in the soil is approximately 50 times that present in the groundwater.

⁹ This is similar to calculating the K_d however, the K_d value is derived for saturated materials where equilibration of the contaminant has occurred between the aquifer and the aquifer matrix i.e. K_d describes the degree of sorption of a particular species in the groundwater to the soil or rock that is in contact with that water.

Table 20: Ratio of PFAS in Soil to Groundwater - Unsaturated Zone¹

Site	Matrix	Relative Amount of PFOS	Relative Amount of PFHxS
P10	Clay	108	NC ²
P13	Gravel	NC ²	11.5
P17	Gravel	55	NC ²

Notes:

- Units soil ug/kg; water µg/L.
- Not calculated due to concentration in soil <LOR.

Although there are only two ratios, PFOS concentrations are significantly higher in the unsaturated soil relative to the groundwater when compared to PFHxS. This agrees with the findings of other investigations, undertaken overseas, into the partitioning of PFAS (e.g. CONCAWE, 2016; AECOM, 2017) as well as the findings of a similar comparison undertaken at RNZAF Base Ohakea (PDP, 2019c). It also appears from the above comparison that fine grained soil (e.g. clay) potentially retains more PFOS than gravel soils. This is to be expected due to the lower permeability of fine soils and the increased surface area for sorption.

The results also indicate that, at these locations, there is potentially a significantly greater mass of PFAS (particularly PFOS, less so for PFHxS) in the unsaturated soil than in the groundwater. Although the values in Table 20 are not directly comparable to K_d values, they can still indicate the concentration of PFOS and (and to a lesser extent PFHxS) is greater in soils in comparison to groundwater. This finding is significant for predictions of future plume behaviour, as leaching of PFAS from the unsaturated soil will likely provide an ongoing and long-term source of PFAS to groundwater.

The area of the base where PFAS has been found in soils is around 20 hectares, and the depth to groundwater is around 5 to 10 m. PFOS + PFHxS was found in soil samples on-site at concentrations up to 0.0026 mg/kg. Based on a typical soil density of 1.33 g/cm³, the mass of PFOS + PFHxS currently in unsaturated soils on-site could therefore be up to around 7 kg.

Groundwater samples collected on-site were of varying depths, the maximum depth was around 30 m and the maximum concentration of PFOS + PFHxS was 2.4 µg/L. Based on a storage value of 0.2, the volume of groundwater under the site is around 1 x 10⁶ m³. Therefore, the mass of PFOS + PFHxS in groundwater under the site is around 1 kg.

Sufficient information is currently not available to calculate partition coefficients or K_d values for the likely plume source areas at the site. It is likely that the rate at which PFAS are leached from the on-site plume source areas into groundwater will remain relatively constant assuming:

- ∴ No additional PFAS is added to the system i.e. through continued use of AFFF;
- ∴ There are no significant changes in infiltration rates at the site (i.e. removal of impervious surfaces covering PFAS impacted soils; and
- ∴ No significant change in groundwater levels and rainfall.

A change of land use to the surrounding catchment including significant fertiliser applications i.e. dairy farming and/or intensive horticulture, could result in changes to soil structure such as changes in pH and cation exchange capacity which could lead to increased leaching rates of PFAS in soil.

7.4.2 Saturated Zone and Spring-fed Streams

Diagram 3 presents a conceptual sketch of the mass balance in the plume, which has been used to understand the existing plume movement and patterns of groundwater flow.

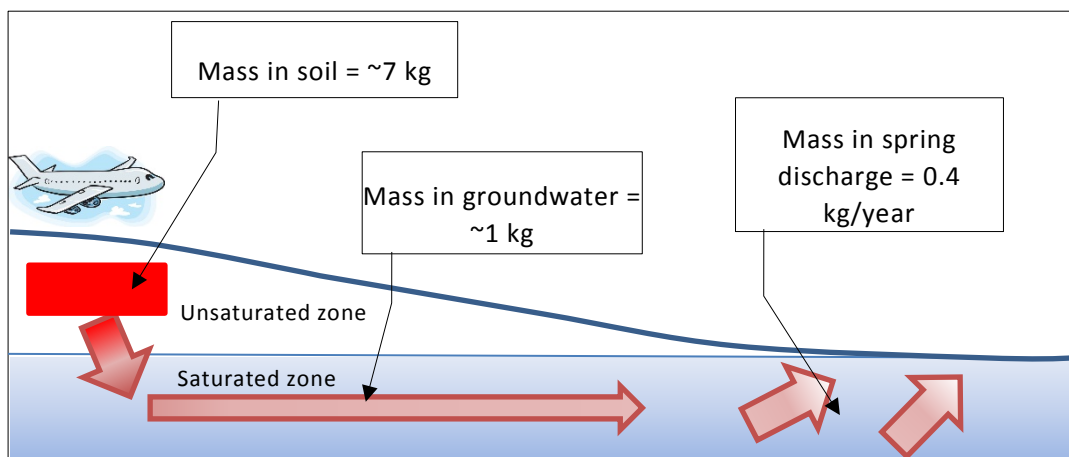


Diagram 3: Conceptual Sketch of Plume Mass Balance

The main groundwater plume of PFAS occupies the following spaces:

- ∴ Within the base an average area of around 20 ha and groundwater concentrations of around 0.3 µg/L across a depth of up to 15 m below the water table, which fluctuates from around 5 – 10 m below ground level in the area of the base. Assuming a porosity of 30%, this corresponds to a mass of around 0.27 kg. Compared to the estimated mass in soils discussed in Section 7.4.1 of around 7 kg, this implies a ratio of mass in soils to mass in groundwater of around 25, which is consistent with the ratios observed in Table 20; and,
- ∴ To the east of the site the main central plume occupies an area of around 200 ha (Figure 7). The average PFOS + PFHxS concentration of all

groundwater samples collected within this area was 0.05 µg/L. In addition, the plume covers an area of approximately 615 ha where groundwater concentrations are, on average, around 0.01 µg/L. Assuming a similar porosity of 30%, the mass of PFAS in the plume in groundwater east of Woodbourne is around 1 kg.

Concentrations of PFOS + PFHxS in the downgradient springs (Doctors Creek and the Fairhall Co-op Drain) have been measured at concentrations up to 0.055 µg/L, which is consistent with the concentrations observed in groundwater located centrally within the plume. The average surface water concentration of PFOS + PFHxS from the sampling (of the Fairhall Co-op Drain and lower section of Doctor's Creek) was 0.045 µg/L.

Flow rates in Doctors Creek and the Fairhall Co-op Drain are variable and respond to changes in groundwater level. A typical flow in Doctors Creek/Fairhall Co-op Drain at its confluence with the Taylor River is around 300 L/s, although higher flows, up to 1 m³/s, have been observed at times of high groundwater levels.

Based on these flow estimates and concentrations, the mass of PFOS + PFHxS exiting the groundwater system into the springs is around 0.4 kg/year. If the concentrations observed during the sampling that are presented in this report are representative of the concentrations through time since the plume has developed, the total mass flowing into surface water via springs would be equivalent to around 14 kg PFOS + PFHxS over the 35 years since AFFF use began at the base. The estimate of 14 kg may represent a lower bound of the potential mass entering surface water through the springs, because higher concentrations of PFOS + PFHxS may have occurred in the past, which would correspond to a greater mass leached.

As noted above, existing data from soil samples and groundwater samples at the site imply that there is 7 kg of mass of PFOS + PFHxS in soil that has not yet leached into groundwater. The mass of AFFF containing PFAS that has left the site since 1980 is not clearly defined, but the information discussed above suggest that the total mass could be in the order of 22 kg, based on 14 kg having exited the groundwater system through the springs, around 7 kg within soils at the base, plus approximately 1 kg in groundwater.

7.5 Plume Model

7.5.1 Objectives of Plume Modelling

A three-dimensional groundwater flow and transport model was developed using MODFLOW and MT3DMS to represent the existing plume and to assist with estimating how the plume may evolve in the future due to changes at the source. The groundwater model simulates the sum of PFOS + PFHxS because they are applicable to the interim drinking water guideline value of 0.07 µg/L.

The key questions that the model sought to address are summarised below:

- ∴ How much PFAS mass (PFOS+PFHxS) is present in the existing plume?
- ∴ What is the likely shape of the existing plume?
- ∴ What and where are the likely key receptors of the plume?
- ∴ If the source of PFAS is depleted via leaching into groundwater, how long will it take to disappear?

The volume and mass of the source inputs are not precisely known. Consequently, the predictions made in this section represent only a general guide to the likely evolution of the plume in future.

Model simulations were 'calibrated' to reasonably match the available observation data and conceptual hydrogeological understanding of the region and the plume at present day. Relevant, available observation data collected from the NZDF sampling investigations and MDC borehole database were incorporated.

7.5.2 Modelling of the Existing Plume

A model of the existing plume was developed based on information regarding concentrations of PFAS in groundwater at the Woodbourne Base (i.e. the source concentration). The flow component of the model was calibrated to flow rates in Doctors Creek and Fairhall Creek and the available information on groundwater levels and gradients so that the pattern of groundwater movement was reasonably represented. In addition, model parameters were also constrained based on the observed concentration of PFAS at downgradient monitoring bores and estimates of the total mass of PFAS leaving the site, which is thought to be around 14 kg over 35 years.

The shape of the existing, observed plume downgradient of the Woodbourne base is relatively well defined (refer to Section 7.2 and Figure 7) and indicates that PFAS originating from the base travels east towards the Old Fairhall Creek and Doctors Creek. It is likely that the contamination in shallow groundwater discharges from the groundwater system into the springs feeding both those surface waterways. However, some PFAS travels beyond the springs and into the confined aquifer beneath Blenheim, albeit at significantly reduced concentrations.

Diagram 4 illustrates the modelled groundwater plume compared to the observed pattern of PFOS and PFHxS contamination for two different scenarios. In general, the groundwater model matches the observed spatial pattern of contamination reasonably closely, implying that the flow directions are represented in the model.

The observed data indicates that the main receptors of contamination are the spring-fed streams that form the headwaters of Old Fairhall Creek and Doctors

Creek and any water supply bores within the plume area. The model can reproduce that conceptual expectation closely and in general, the spring discharges exert a strong control on groundwater movement in the area. Note that the groundwater model is steady state and represents average groundwater levels. In reality, groundwater levels and flow directions may vary at different groundwater level elevations. These effects are not represented in the model, but it is not expected to be significant in terms of the main mass of the plume. Consequently, the model does not suggest that there may be other significant receptors. The degree in which these receptors could change over time would be a factor of land use change e.g. residential development which results in increased number of water takes of groundwater, rather than a change in the groundwater plume behaviour.

The spatial extent of the plume can be reasonably simulated by the model.

The observed field concentrations downgradient of the base can be simulated from a relatively small source concentration (less than 1 µg/L) which implies a relatively low mass of PFAS leaving the site (15 kg over 35 years).

The modelled value is generally consistent with the estimated value described in Section 7.4 estimated to be around 14 kg over 35 years. The model also indicates that ~ approximately 1 kg of mass is within the saturated zone of the aquifer between the base and the springs, which is consistent with the estimates discussed in Section 7.4.2.

Based on available data at the site, there is likely to be a mass of PFAS in the soil that has yet to leach to groundwater. Note that the model does not imply there is a large mass of PFAS within the existing plume (around 1 kg, based on the model indicating a 15 kg total loss over 35 years).

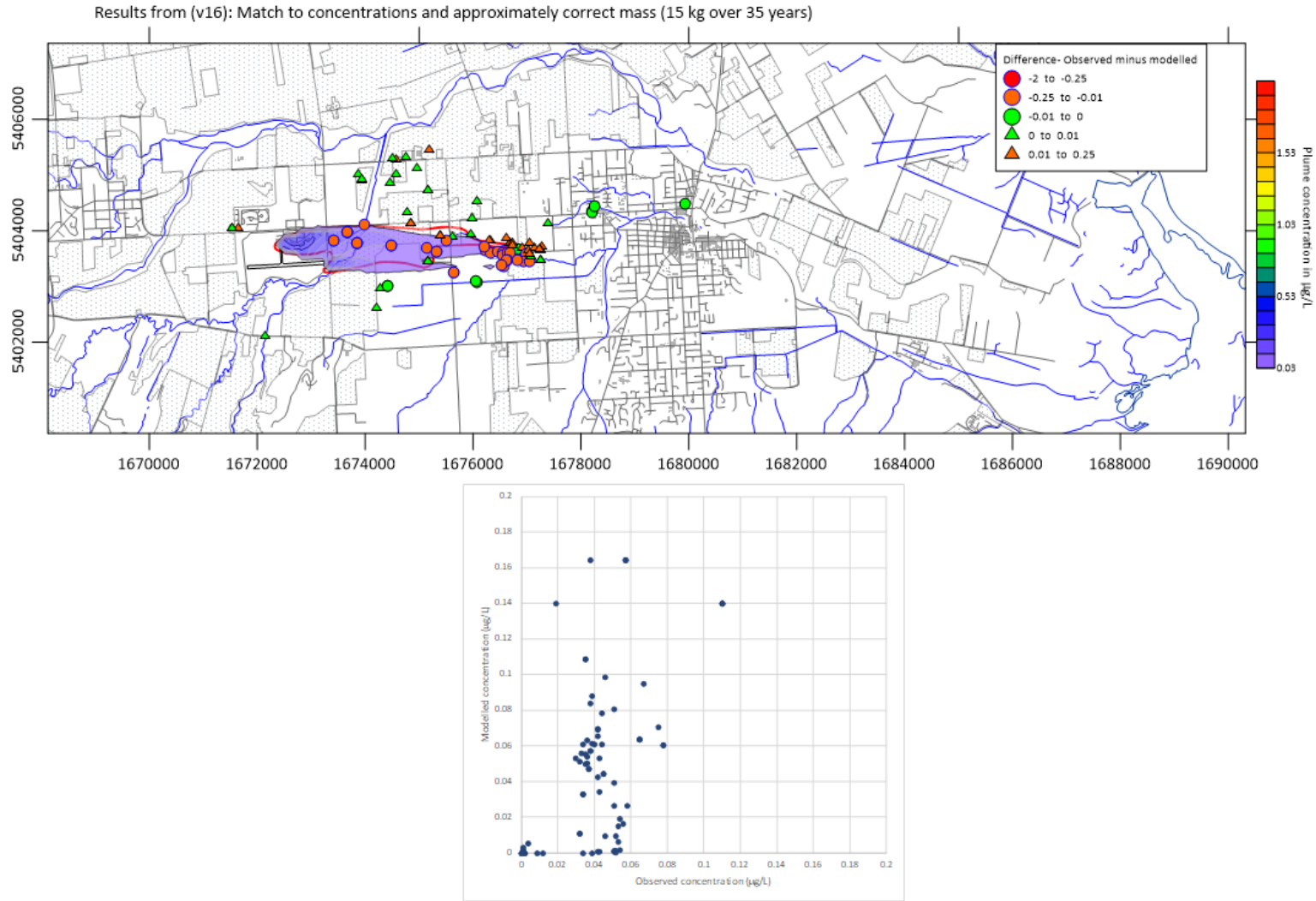


Diagram 4: Map of modelled plume extents and observed plume outline (red line). Chart below the map summarises the modelled concentrations compared to the observed concentrations.

7.5.3 Future Plume Evolution

The most conservative approach to considering the future plume evolution is to assume that there is a mass of PFOS and PFHxS still to enter the aquifer. Based on the modelled results where the current concentration in groundwater is reasonably represented, over 35 years around 13 kg of PFOS + PFHxS has leached from the unsaturated zone into groundwater. If that rate of leaching remains constant (0.4 kg/year), then a total mass of around 7 kg, could take 20 years to leave the site.

This long-term estimate is a possible scenario and it is important to highlight that there is considerable uncertainty around the above estimate due to variations in soil PFAS concentrations and potential leaching rates into groundwater. Therefore, a greater mass of PFAS may be present in the soils under the site, which could take a longer time to leach into groundwater prolonging the existence of the plume. However, without more detailed information on the use of AFFF at the base, it is not possible to constrain the future plume evolution to a more likely timeframe. Therefore, as a conservative approach the plume will remain largely constant for the foreseeable future.

The shape of the plume is not expected to change in the foreseeable future; due to the nature of the hydrogeological setting of the area. The conceptual understanding of the hydrogeology, supported by the numerical modelling, is that the spring fed streams in the Bells Road – Battys Road area create a drainage effect on the groundwater that will limit the width of the main plume as it approaches the spring discharge area. The exit of plume mass into these spring-fed streams also constrains the eastwards groundwater plume migration such that lower concentrations are expected to occur east of Purkiss Street and any higher concentrations are expected to be less common. Therefore, the plume outline illustrated in Diagram 4 is expected to provide a useful guide to the future shape of the main plume emanating from the base. It is not expected to spread laterally or to extend further beyond the eastern end of the spring discharge area.

7.5.4 Potential Impact on Receptors in the Short Term

The extent of the receptors that might be adversely affected by the current and future behaviour of the plume in the short term is likely to remain similar to the current situation, although seasonal variability may result in some higher or lower PFAS concentrations than have been observed to date.

This is however dependant on the assumptions that:

- ∴ Foams which contain PFOS and PFHxS or have the potential to degrade into these compounds are not used on the base;
- ∴ There is no significant change in land use in the plume area;

- ∴ No significant groundwater takes which might alter the plumes behaviour/groundwater flow directions;
- ∴ No significant change to the drinking water guideline with respect to PFAS (either lower or increases); and,
- ∴ New wells for drinking water are not established in the plume area.

8.0 Updated Conceptual Site Model

A PFAS-specific conceptual site model (CSM) was prepared by Aurecon following the completion of the DSI (Aurecon, 2018). This was updated based on the findings included in this report. The information in the CSM is displayed in flow chart view and pictorial view (illustrated in Figure 8 and Figure 9).

The following complete pathways have been identified through the PFAS investigations:

- ∴ PFAS contaminated groundwater; and,
- ∴ PFAS contaminated surface water.

The following receptors that are affected from the above pathways are:

- ∴ Groundwater users;
- ∴ Consumers of home-grown animal products;
- ∴ Freshwater biota consumers; and,
- ∴ Aquatic ecosystems.

The information used to inform the CSM has been based on the work undertaken during the DSI (Aurecon, 2018), and the off-site sampling investigations (PDP, 2018a; PDP, 2018b; PDP, 2018c; PDP, 2018d; PDP, 2019).

At present, there is no evidence that other significant sources of PFAS exist at the site.

9.0 Risk Assessment

A Tier 1 human health and ecological risk assessment, based on the updated CSM, has been undertaken to determine the likelihood that the identified sources pose a risk to the receptors. The risk assessment has been undertaken using New Zealand adopted PFAS guidelines.

9.1 Groundwater Users

9.1.1 Human Health Receptors

The current on-site groundwater wells used for drinking water were sampled by Aurecon (2018) six times between August 2018 and January 2019. PFAS was not

reported above the LOR in any sample. The current drinking water groundwater wells are located upgradient of the groundwater wells previously used for on-site drinking water supply and where PFAS have been detected. Currently, there is no exposure to PFAS via drinking water to base personnel.

Extensive groundwater sampling from private wells downgradient of the site has confirmed the presence of a groundwater PFAS plume. Of the 203 private groundwater wells where samples were collected and analysed for PFAS, three wells had one or more samples that had a concentration of PFOS + PFHxS that exceeded the drinking water guideline of 0.07 µg/L. A total of seven off-site wells had a concentration of PFOS + PFHxS greater than 0.06 µg/L, five of those wells were used for drinking water. Groundwater in the Woodbourne/Blenheim area is heavily relied on for drinking water, and therefore the exposure pathway of ingesting PFAS contaminated drinking water is complete in some locations.

Initially the trigger to account for UOM for this investigation was 0.05 µg/L, and this value was previously used to assess the risk associated with PFAS in drinking water. As the investigation progressed and additional data collected, the trigger to account for UOM was redefined and determined as 0.06 µg/L.

Early in the investigation, a total of 14 properties that used drinking water from groundwater bores that had a PFOS + PFHxS concentration over 0.05 µg/L were offered alternative drinking water supply. Only 11 properties are currently receiving alternative drinking water supply as some stakeholders, acknowledging the risk to be low, have declined the alternative drinking water supply. The maximum PFOS + PFHxS concentration reported in groundwater from those three properties that declined alternative drinking water was below the new trigger value of 0.06 µg/L.

Although the exposure pathway was complete, the risk has been managed through providing alternative drinking water supply to properties where groundwater samples have exceeded the drinking water guideline or had a PFOS + PFHxS concentration above 0.06 µg/L. This risk should be managed long-term as PFAS concentrations are modelled to remain relatively constant with time. This assessment has not considered the suitability of the groundwater within the plume area for drinking water from new takes that may occur in the future.

In addition to the above, exposure to PFAS is still occurring at properties which have detectable PFAS concentrations in their drinking water supply that are not currently receiving an alternative water supply. However, the maximum PFOS + PFHxS concentration recorded in groundwater samples collected from these properties is below 0.06 µg/L. This concentration is currently lower than the interim drinking water guidelines (which is 0.07 µg/L), and therefore the risk to human health from consumption of this water is considered to be low, based upon our current understanding of the toxicology of these compounds. Multiple rounds of groundwater sampling of the MDC water supply bores have also been

conducted. Except for one groundwater sample; no PFAS was reported above the LOR in the samples collected from the MDC water supply bores. One sample reported a concentration of PFHxS (0.0014 µg/L) that was very close to the LOR of 0.001 µg/L and was much lower than the drinking water guideline (0.07 µg/L). The risk associated with PFAS concentrations in the MDC drinking water supply is therefore negligible.

9.2 Surface Water Receptors

9.2.1 Ecological Receptors

Surface water sampling has confirmed the presence of PFAS in waterways downgradient of the site: Old Fairhall Creek, Fairhall Co-op Drain, Doctor's Creek and Taylor River. The highest PFOS + PFHxS concentrations were found in surface water samples collected from Old Fairhall Creek. No surface water samples exceeded the 95% ecosystem protection guideline, although this guideline is not protective against the bioaccumulation and/or biomagnification of PFAS in aquatic organisms, however it is in line with the proposed amendments to the 99% protection guideline as discussed in Section 5.2. Of the 91 surface water samples collected off-site; 43 had a PFOS concentration above the LOR, which exceeds the existing 99% ecosystem protection guideline (HEPA, 2018).

Elevated concentrations of PFAS were reported in the fish flesh, liver and roe of fish caught within the Old Fairhall Creek and Taylor River. Significantly higher PFOS + PFHxS concentrations were found in fish samples collected from the Old Fairhall Creek compared to samples from the Taylor River. The sampling results indicate that PFAS are accumulating within the tissues of fish living within the Old Fairhall Creek and Taylor River. As some PFAS are suspected to be biomagnified up the food chain it is possible that apex predators may contain higher concentrations of PFAS. PFAS was also found in a fish roe sample collected from the Taylor River, which poses a risk of PFAS being transferred through the generations. No fish roe samples were collected from Old Fairhall Creek, however the risk is present as much higher PFAS concentrations were found in the fish samples collected from Old Fairhall Creek. The risk of bioaccumulation and/or biomagnification in fish within the Ōpaoa River and Omaka River is much lower in comparison to the fish in Old Fairhall Creek and Taylor River.

PFAS was also confirmed albeit at lower concentrations, in one fish sample collected from the Ōpaoa River, located further downstream from the site. No PFAS was reported above the LOR in the fish samples collected from the upstream reference site in the Omaka River. No PFAS was reported above the LOR in the water samples collected from either site. As the 99% ecosystem protection guideline is below the LOR, it is unclear whether the surface water samples collected from the Ōpaoa River and the Omaka River were below that guideline.

Overall bioaccumulation has been observed in fish downstream of the base, however it is difficult to assess the ecological risks of PFAS bioaccumulation as there is insufficient information on the impacts of these substances within New Zealand ecosystems.

9.2.2 Human Health Receptors

No surface water samples exceeded the recreational water quality/contact guideline, therefore accidental ingestion of PFAS impacted surface water by recreational users is considered unlikely to pose a risk to human health.

The average PFOS concentration of all fish samples analysed from the Old Fairhall Creek was 201 µg/kg. The MPI consumption advice is that children should not consume fish at this concentration and adult consumption should be limited to one serving per month. According to MPI (2018), the average consumption of freshwater fish by adults is less than twice a month.

The average PFOS concentration of all fish samples analysed from the Taylor River was 16 µg/kg, this concentration is above the FSANZ trigger value for further investigation, however, it does not warrant consumption advice following the MPI guidelines.

The fish sample collected from the Ōpaoa River did not exceed the FSANZ trigger value for further investigation and the MPI consumption guidelines. Therefore, based on the sampling conducted, there is a lower potential for fish in this area to accumulate PFAS above concentrations that would be of concern to human health.

Significantly higher PFAS concentrations have been found in the fish liver samples in comparison to the corresponding flesh samples. This could pose a high risk to consumers of fish liver from the Old Fairhall Creek and Taylor River. However, MPI (2018) advises that the fish should be thoroughly gutted prior to consumption which may minimise exposure to PFAS via this pathway.

Concentrations of PFHxS + PFOS in fish collected from the Old Fairhall Creek exceeded the MPI advisory limit for consuming one serving per month (for an adult). Currently there is no evidence that anyone is regularly consuming fish from this location and this exposure pathway may be incomplete.

9.3 Soil

9.3.1 Human Health Receptors

No on-site soil samples exceeded the soil human health screening values for industrial/commercial land use. Therefore, no risk has been identified from exposure to PFAS impacted soil on-site.

9.3.2 Ecological Receptors

The soil samples collected on-site do not exceed the current or interim HEPA (2018) ecological guidelines for ecological direct and indirect exposure. The interim soil ecological indirect exposure (i.e. exposure through the consumption of organisms in direct contact of PFAS impacted soils) guideline is currently under review in the HEPA (2019) PFAS NEMP Version 2.0 Draft PFAS. The soil samples collected on-site are also below the draft ecological indirect exposure guideline value. Based on this information, the risk to ecological receptors that are directly or indirectly exposed to PFAS impacted soil at the site is considered low.

9.4 Chicken Eggs

9.4.1 Human Health Receptors

Chicken eggs were collected from three properties adjacent to the site. PFAS concentrations were above the LOR in one or more samples from each site. No egg samples exceeded the FSANZ trigger points for further investigation. The potential intake of PFHxS and PFOS was modelled by MPI for these properties to include the consumption of eggs produced at these properties. The model suggested that there was unlikely to be a food safety concern associated with the consumption of eggs or other home grown produce at these sites.

9.4.2 Ecological Receptors

The PFAS NEMP 2.0 Draft (HEPA, 2019) includes a terrestrial biota ecological guideline for bird eggs to protect the survival and development of bird eggs and chicks. The draft guideline value for the sum of PFOS + PFHxS is 0.2 µg/kg and is an indication of the level at which adverse effects may start to occur. This investigation however targeted unfertilised poultry eggs for the purpose of assessing risks to human health, for this reason the draft guidelines have not been applied to the chicken egg sample results.

9.5 Risk Assessment Limitations

The collection of fish was limited to one sampling round. The small sample size increases the degree of uncertainty pertaining to collecting a representative sample for each species. In some cases, only one individual of each species was collected and analysed from each site. The average PFOS concentration of fish tissue samples were calculated for the purpose of comparing fish results to the MPI (2018) consumption guidelines. Due to the small sample size, the average PFOS concentration was calculated for all species collected from each site.

The collection of chicken eggs was limited to one round of sampling. As no samples exceeded the FSANZ trigger value, further sampling was not conducted. There is a degree of uncertainty associated with this assessment as PFAS concentrations in the chicken eggs could vary.

10.0 Summary and Conclusions

Environmental investigations at RNZAF Base Woodbourne have identified PFAS in soil and water on-site, and in water in the surrounding environment and neighbouring properties. PFAS was also found in animal tissue of terrestrial and aquatic biota downgradient of the site. The sampling investigations completed between December 2017 and September 2018 included several rounds of sampling both on-site and off-site. The sample media included groundwater, surface water, soil, sediment pore water, and terrestrial and aquatic animal tissue. During the investigations:

- ∴ PFAS was detected in all media sampled on-site and off-site. PFOS and PFHxS were the most prevalent compounds;
- ∴ PFAS was detected in groundwater across an area extending approximately seven kilometres east of Woodbourne. PFAS was detected in surface water up to six kilometres east of Woodbourne. The total PFAS groundwater plume, where concentrations exceed the LOR is estimated to cover an area of approximately 815 hectares. The area of the plume where concentrations exceed the guideline threshold PFOS + PFHxS greater than 0.06 µg/L, adopted guideline value for drinking water when accounting for uncertainty of measurement) is approximately 200 hectares;
- ∴ Exceedances of applicable guidelines and trigger values were observed in groundwater and fish tissue samples collected off-site. PFAS was not reported above the LOR in any groundwater samples collected from on-site drinking water wells;
- ∴ Of the 203 private groundwater wells off-site that had water samples collected and analysed for PFAS; seven wells had a concentration of PFOS + PFHxS greater than 0.06 µg/L. Five of these wells were used for drinking at the time of the first round of sampling for that property. All the households that previously took domestic water supply from these affected wells are currently supplied with an alternative drinking water supply;
- ∴ PFAS was not reported above the LOR in the groundwater samples collected from the MDC water supply wells for Blenheim for all of the PFAS analysed, except for a single sample for GW117. The one groundwater sample from GW117 that did positively detect PFAS had a concentration of PFHxS which was near the LOR. The concentration of PFHxS was significantly (more than an order of magnitude) lower than the drinking water guideline;
- ∴ The median concentrations of PFOS, PFHxS, PFOS + PFHxS and perfluorooctanoic acid (PFOA) were higher in groundwater samples

collected on-site than the groundwater samples collected off-site. Of the groundwater and surface water samples collected off-site, higher concentrations of PFOS + PFHxS were observed at sample locations near Old Fairhall Creek. Lower concentrations of PFOS + PFHxS in groundwater were observed to the north near Old Renwick Road.

- ∴ Significantly higher PFOS + PFHxS concentrations were found in fish tissue samples collected from Old Fairhall Creek than in samples collected from other streams and rivers downstream of Woodbourne (including the Taylor River and Ōpaoa River). PFAS was not reported above the LOR in the fish tissue samples collected from the reference site upstream of Base Woodbourne;
- ∴ The average PFOS concentration of all fish samples analysed from the Old Fairhall Creek was 201 µg/kg. The MPI consumption advice is that children should not consume fish from Old Fairhall Creek and adult consumption should be limited to one serving per month. Currently there is no evidence that anyone is regularly consuming fish from this location and therefore this exposure pathway may be incomplete;
- ∴ On-site there is significantly greater mass of PFAS (particularly PFOS) in the unsaturated soil¹⁰ than in the groundwater; and,
- ∴ There is some evidence that transformation of other PFAS into measurable compounds (such as PFHxS) may be occurring. However, the evidence is inconclusive and other factors cannot be ruled out as contributing to the results observed.

A three-dimensional groundwater flow and transport model was developed using MODFLOW and MT3DMS to represent the existing PFAS plume (by modelling the PFOS + PFHxS concentrations) to assist with estimating how the plume may evolve in the future.

Modelling the plume behaviour has shown:

- ∴ The observed shape and concentration of the plume was reasonably simulated by the groundwater model, implying that the groundwater model can be used for predictive modelling. The model suggests that the plume is currently in a stable state; and,
- ∴ The main receptors of PFAS contaminated groundwater are the spring-fed streams that form the headwaters of Old Fairhall Creek and Doctors Creek, and any water supply bores within the plume area.

The following conclusions have been drawn following interpretation of the groundwater results and the plume modelling plume:

¹⁰ Unsaturated soil refers to soil above the water table.

- ∴ The on-site sampling results indicate that there is significantly greater mass of PFAS in the unsaturated soil than in the groundwater. The PFAS associated with the unsaturated zone acts as the plume source;
- ∴ The behaviour and the spatial extent of the plume is likely to remain relatively constant for the foreseeable future (i.e. the next few decades), assuming that:
 - No additional PFAS sources are released into the soil on the site or into the groundwater plume;
 - No significant change in land use above the plume resulting in more people drinking PFAS contaminated water;
 - No significant change in groundwater abstraction which could potentially alter the direction of groundwater flow; and,
 - No substantial rises or falls in groundwater levels occur.

In order to cover a large investigation area in a short time frame, the groundwater sampling programme utilised existing groundwater abstraction wells. A number of well depths were not known however they are all expected to be less than 30 metres deep. The variability and uncertainty in the abstraction depths adds variability to the monitoring results and must be kept in mind when interpreting the sampling results, and conclusions that can be drawn from the data.

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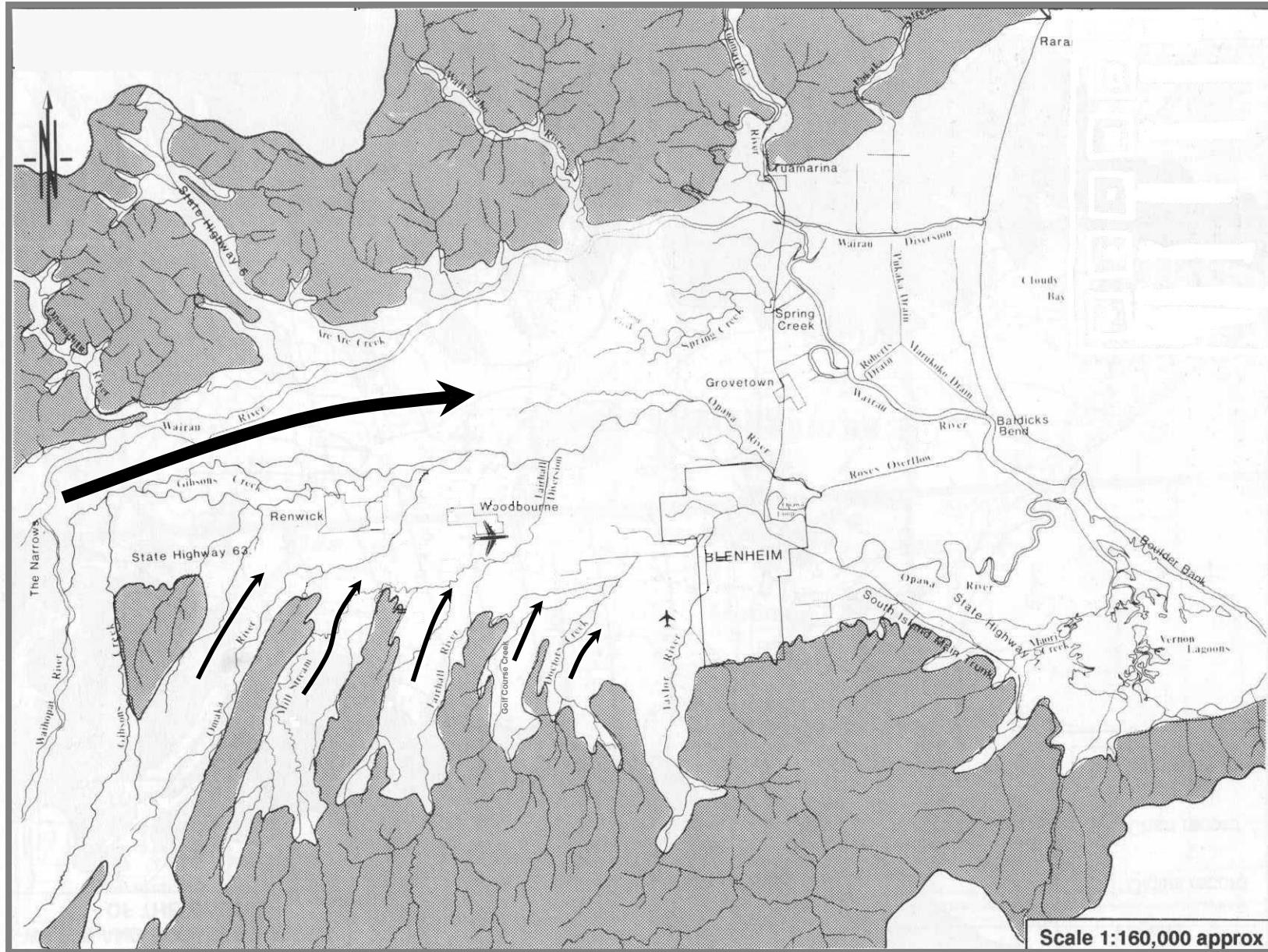
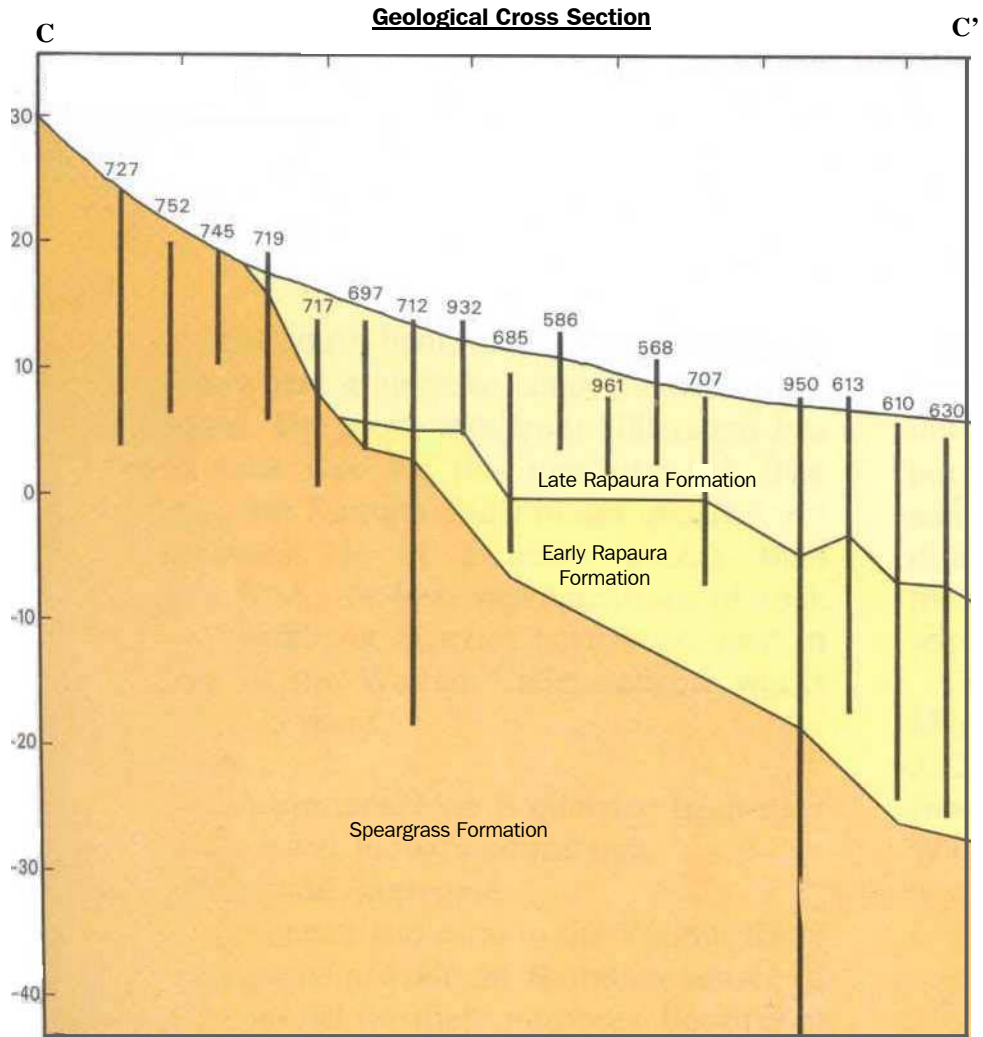


Figure 1: Location Plan Showing the Orientation of Rivers that formed the Wairau Plain Strata (unshaded area). Source: modified from MDC, 1988.



Cross Section Location

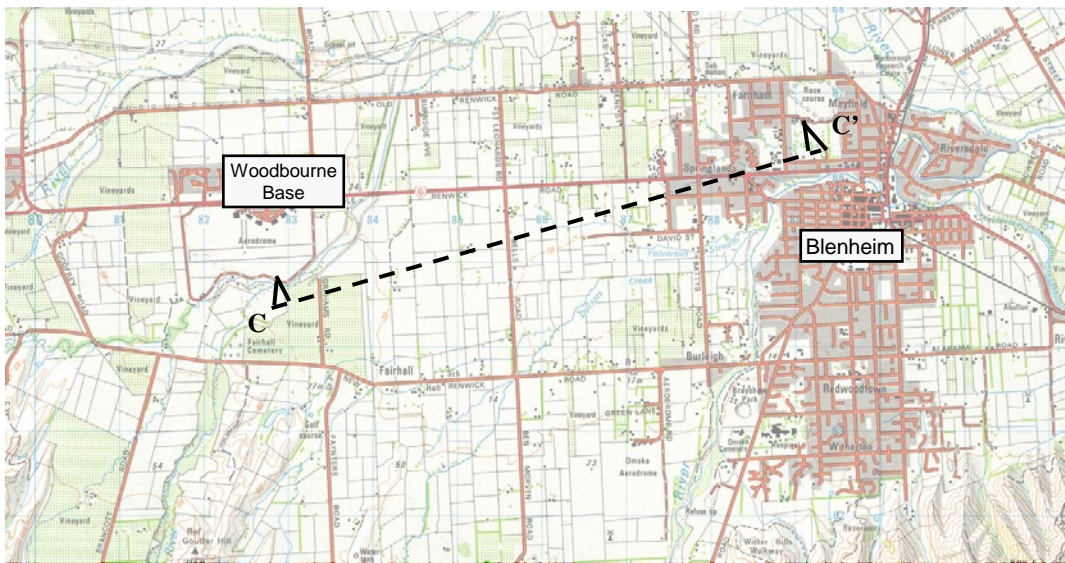
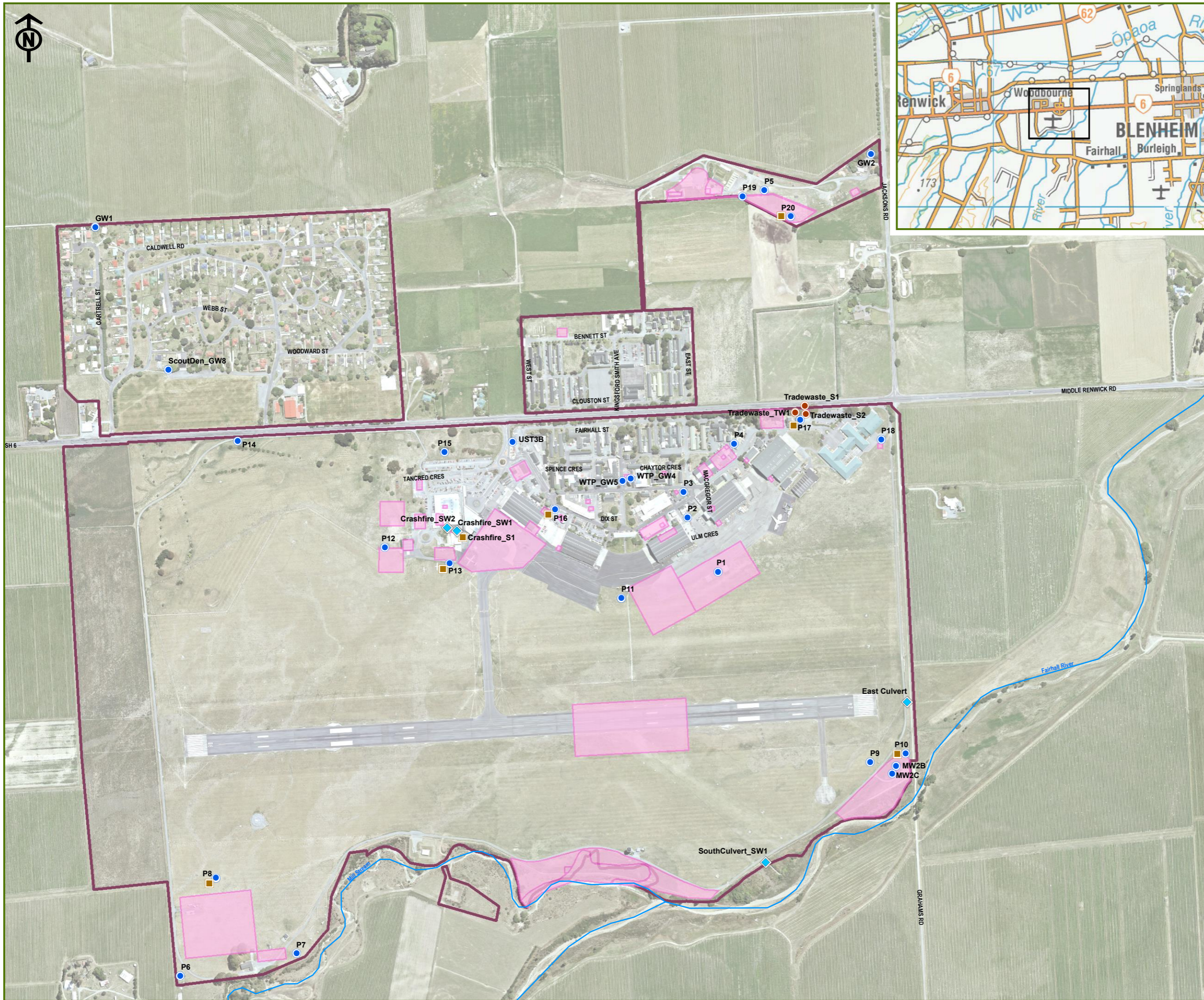


Figure 2: Geological Cross Section.

Source: Cross-section modified from MDC, (1988); location map sourced from Land Information New Zealand



- KEY :**
- Sample Location**
- ◆ Surface water
 - Groundwater
 - Soil
 - Tradewaste
 - River line
 - PFAS Related HAIL Site
 - RNZAF Base Woodbourne

SOURCE:
Aerial imagery flown 2015/2016 sourced from the LINZ data service
<https://data.linz.govt.nz/layer/marborough-02m-rural-aerial-photos-2015-16/> and licensed for re-use under the creative commons attribution 4.0 New Zealand licence.
Topographic information supplied by LINZ.

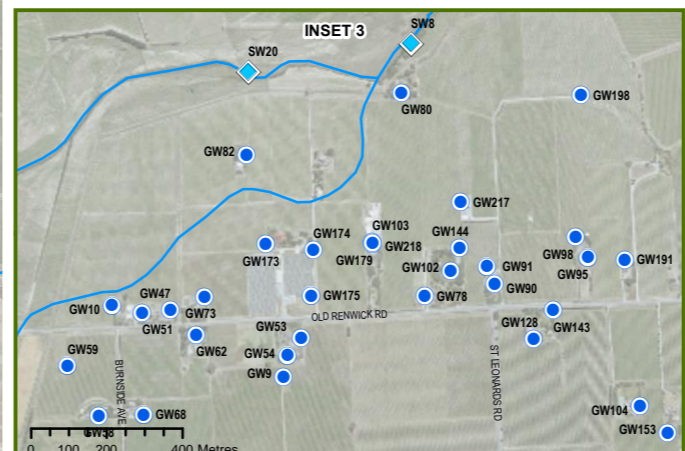
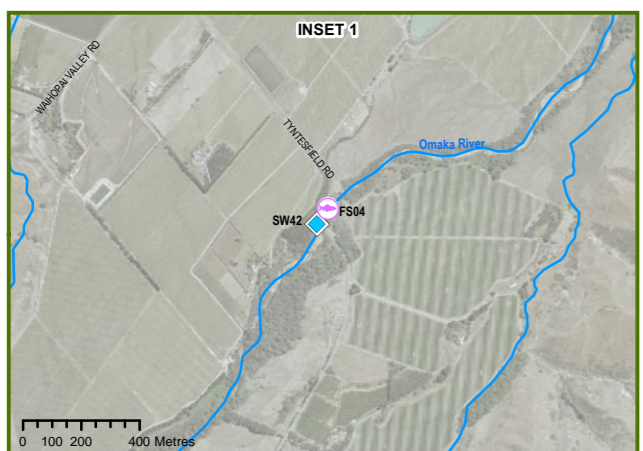
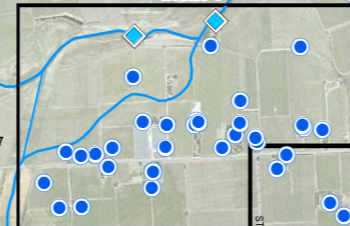
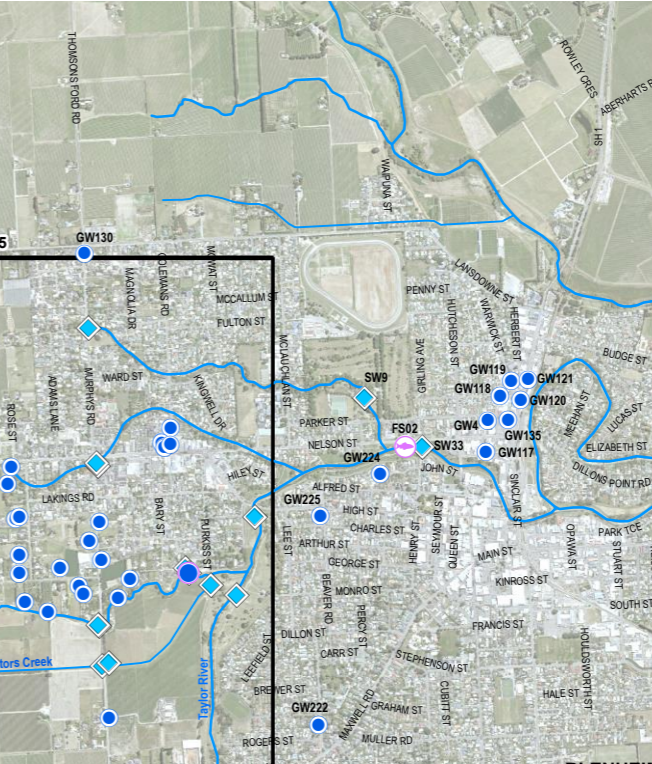
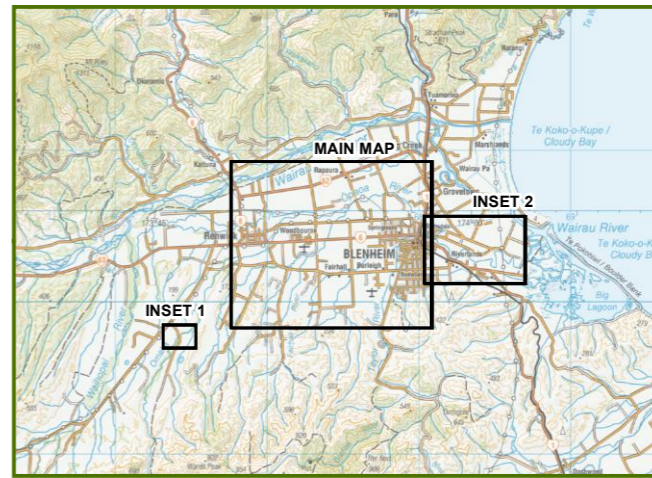
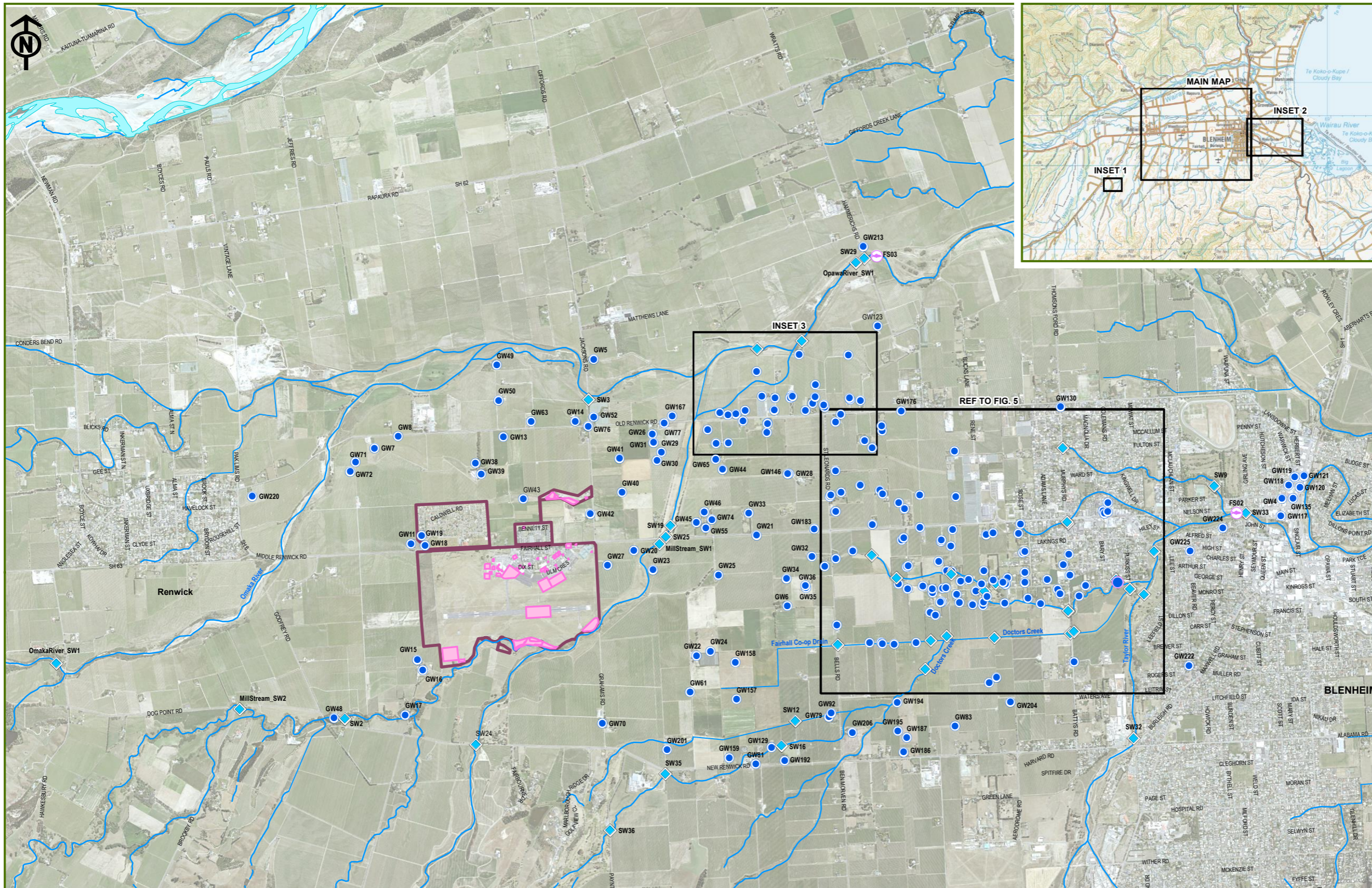
NO.	REVISION HISTORY	DATE
A	FINAL	JUL 19



PROJECT NAME:
RNZAF BASE WOODBOURNE
PFAS INVESTIGATION:
COMPREHENSIVE
SITE INVESTIGATION REPORT

FIGURE TITLE:
ONSITE SAMPLE LOCATIONS

SCALE: 1:7,500 (A3)	FIGURE NO.: 3	ISSUE NO.: A
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- KEY :**
- Sample Location**
- ◆ Surface water
 - Fish
 - Groundwater
 - Pore water
 - PFAS Related HAIL Site
 - River line
 - RNZAF Base Woodbourne

SOURCE:
Aerial imagery flown 2015/2016 sourced from the LINZ data service
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Cadastral information supplied by LINZ, dated 1 Aug 2017.

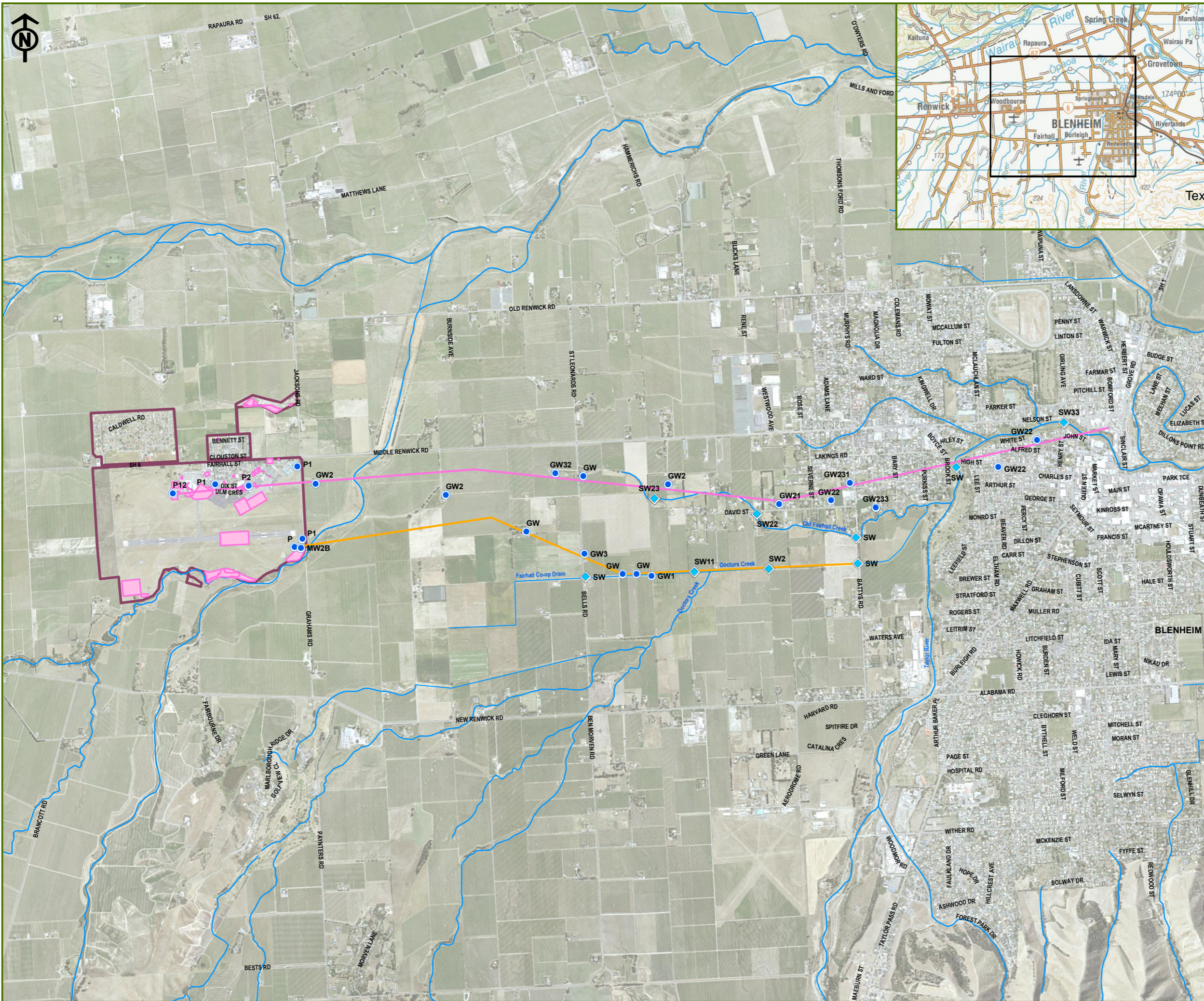
NO.	REVISION HISTORY	DATE
A	FINAL	JUL 19



PROJECT NAME:
RNZAF BASE WOODBOURNE
PFAS INVESTIGATION:
COMPREHENSIVE
SITE INVESTIGATION REPORT

FIGURE TITLE:
OFFSITE SAMPLE LOCATIONS

SCALE: 1:40,000 (A3)	FIGURE NO.: 4	ISSUE NO.: A
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KEY :

- Sample Location**
- ◆ Surface water
 - Groundwater
 - Transect 1
 - Transect 2
 - PFAS Related HAIL Site
 - River line
 - RNZAF Base Woodbourne

SOURCE:
Aerial imagery flown 2015/2016 sourced from the LINZ data service
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Cadastral information supplied by LINZ, dated 1 Aug 2017.

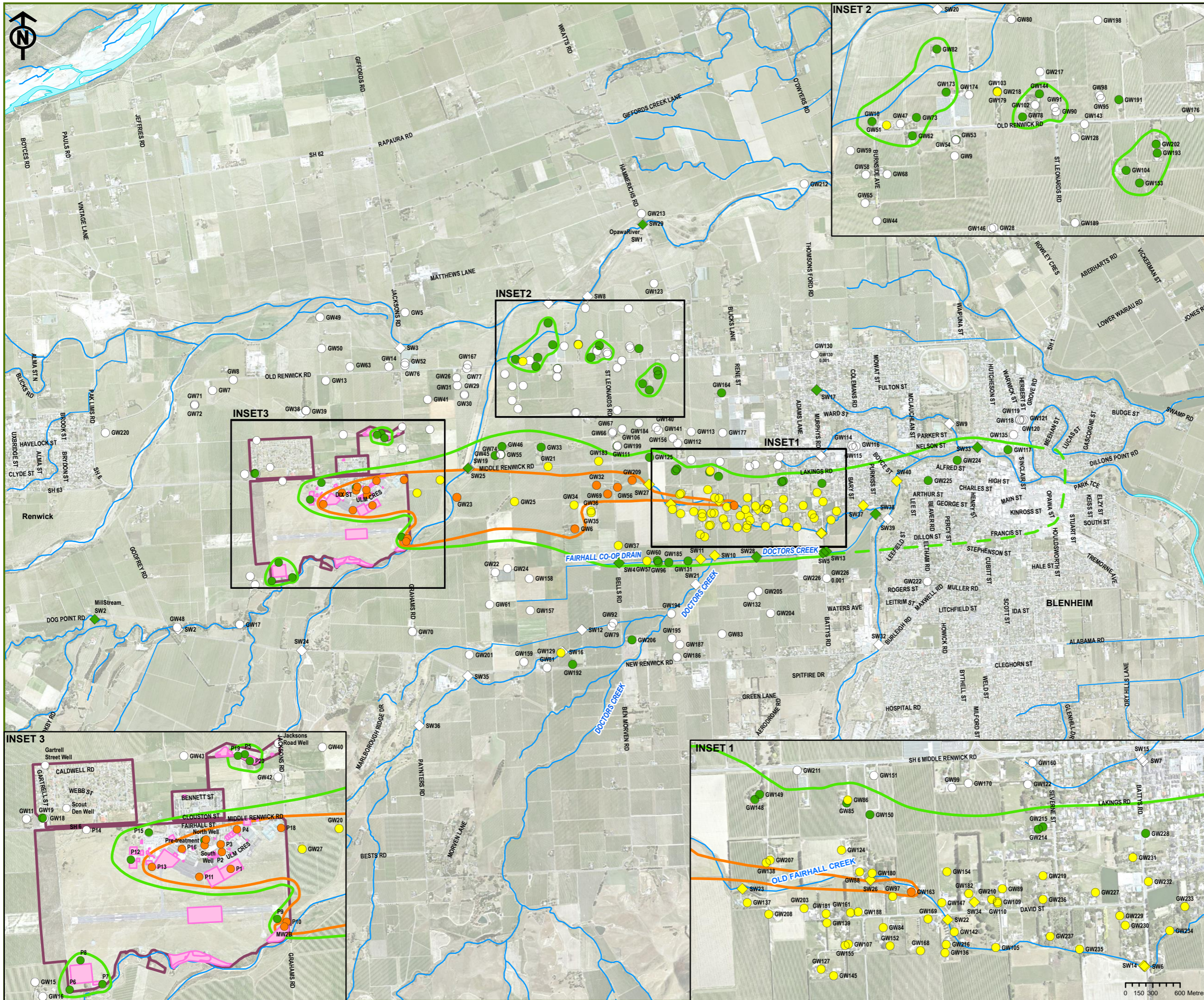
A	FINAL	JUL 19
NO.	REVISION HISTORY	DATE



PROJECT NAME:
RNZAF BASE WOODBOURNE
PFAS INVESTIGATION:
COMPREHENSIVE
SITE INVESTIGATION REPORT

FIGURE TITLE:
GROUNDWATER TRANSECT
LOCATION

SCALE: 1:30,000 (A3)	FIGURE NO.: 6	ISSUE NO.: A
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- KEY :**
- All Groundwater Samples (Max Sum PFHxS + PFOS Results) in ug/L**
- 0.001
 - 0.002 - 0.019
 - 0.02 - 0.06
 - 0.061 and Above
- All Surface Water Samples (Max Sum PFHxS + PFOS Results) in ug/L**
- ◇ < 0.001
 - ◇ 0.002 - 0.019
 - ◇ 0.02 - 0.058
- PFAS Related HAIL Site
 - ▭ Inner Plume
 - ▭ Outer Plume
 - ▭ Estimated Plume
 - ▭ RNZAF Base Woodbourne

SOURCE:
Aerial imagery flown 2015/2016 sourced from the LINZ data service <https://data.linz.govt.nz/layer/marlborough-02m-rural-aerial-photos-2015-16/> and licensed for re-use under the creative commons attribution 4.0 New Zealand licence. Topographic information supplied by LINZ.

NO.	REVISION HISTORY	DATE
A	FINAL	NOV 19

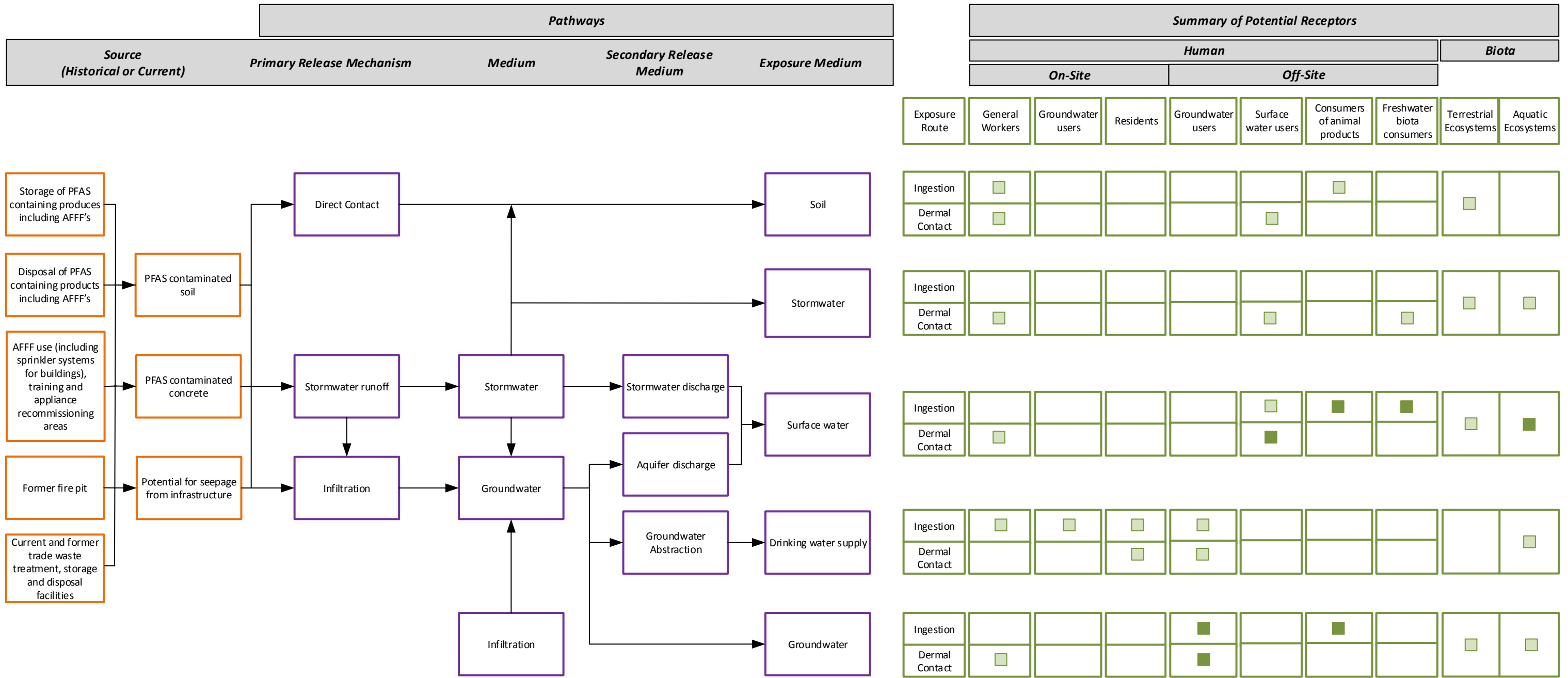


PROJECT NAME:
RNZAF BASE WOODBOURNE
PFAS INVESTIGATION:
COMPREHENSIVE
SITE INVESTIGATION REPORT

FIGURE TITLE:
ALL STAGES GROUNDWATER
AND SURFACE WATER
MAX RESULTS (PFHXS + PFOS)

SCALE: 1:40,000 (A3)	FIGURE NO.: 7	ISSUE NO.: [A]
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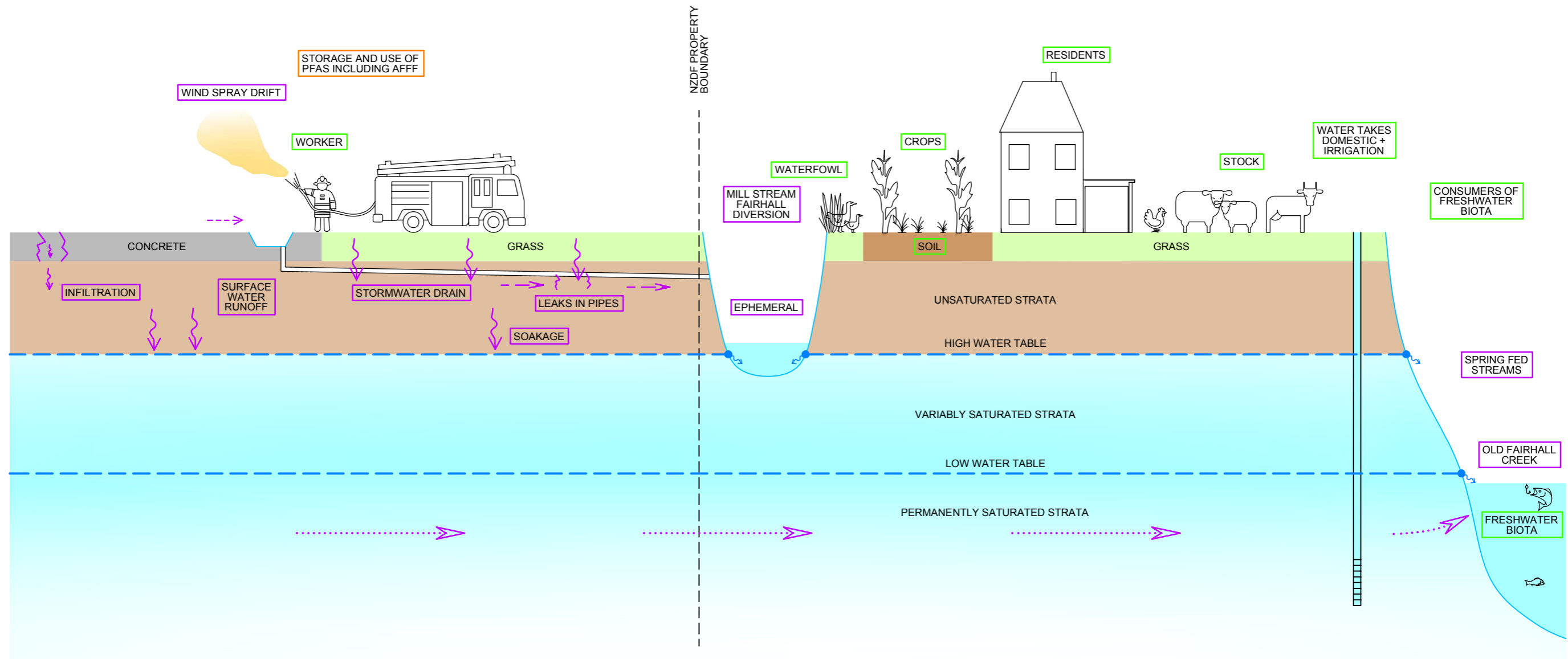
Figure 8: Conceptual Site Model – RNZAF Base Woodbourne*



Key:

- Complete Pathway
- Potentially Complete Pathway
- Incomplete Pathway
- N/A Addressed under the Health and Safety at Work Act, 2015

*Relates to use, storage and disposal of AFFF for firefighting and firefighting training only



NOTE:
 SOURCES, PATHWAYS AND RECEPTORS ARE
 SHOWN FOR EASE OF DISPLAY AND DO NOT
 REPRESENT THEIR ACTUAL LOCATION.

FIGURE 9 : RNZAF BASE WOODBOURNE - PFAS CONCEPTUAL SITE MODEL

KEY	
	SOURCE
	PATHWAY
	RECEPTOR

Appendix A

AFFF at Woodbourne

AFFF

In order to understand the presence of PFAS in the AFFF currently used at Woodbourne, and provide insight into the potential future composition of the plume, AFFF raw product samples were collected from Woodbourne during the 2018 sampling investigations. A sample was collected of two products Tridol S6 and Ansulite 3%.

Only the Ansulite sample (WBN BLK 005) had a concentration of PFAS that was above the LOR. This sample had a 6:2 FTS concentration of 26,000 µg/kg. 6:2 FTS is not the active ingredient of AFFF. It is believed to be present in AFFF either as an unintended by-product of the active ingredient and/or a daughter product of the degradation of the active ingredient.

There was no PFAS above the LOR in the Tridol S6 sample (WBN_BLK_003). Because the lowest LOR in this analysis was 5,000 µg/kg, other measurable PFAS compounds may have been present at lower concentrations.

The AFFF samples were also analysed by a second laboratory at lower LORs as part of the analysis method described in Section 4.2. When analysed at these lower LORs, a larger range of compounds were reported (Table A-2).

Total Oxidisable Precursor Assay (TOPA)

To better understand how firefighting foams used at NZDF sites might degrade and transform over time, a Total Oxidisable Precursor Assay (TOPA) analysis was conducted on a variety of AFFF samples from several NZDF sites. The TOPA analysis assists with simulating how PFAS in AFFF may oxidise and degrade over time. However, it is important to note that the conditions created during TOPA may never actually occur in the natural environment therefore TOPA should be considered to provide an indication of potential degradation of PFAS only.

The results of the TOPA analysis for the samples collected from Woodbourne are provided in Table A-2.

A significant increase in PFCAs such as PFPeA, PFHxA, PFHpA, and PFBA was observed in both AFFF samples (Tridol S6 and Ansulite). Of these compounds, PFBA, PFPeA, and PFHxA were not present above the LOR in the pre-TOPA analysis for the Tridol S6 sample (WBN_BLK003). PFBA, PFPeA, and PFHxA were present in the pre-TOPA results of the Ansulite sample (WBN_BLK005) however at concentrations that were significantly lower in comparison to the post-TOPA results.

The concentration of PFOA significantly increased post-TOPA. WBN_BLK_003 (Tridol S6) had a pre-TOPA PFOS concentration of 26 µg/kg. However, no PFOS was present above the LOR (200 µg/kg) in the post-TOPA results. PFOS was below the LOR in both the pre-TOPA and post-TOPA Ansulite sample (WBN_BLK005). All four fluorotelomer compounds were not present in concentrations above the LOR (200 µg/kg) in the post-TOPA results.

(Note that the LOR post-TOPA is considerably lower than pre-TOPA.)

Table A-1: Aqueous Film Forming Foam (AFFF) Sampling Results¹

Sample Name	WBN_BLK_003_1_200218	WBN_BLK_005_1_200218
Product Description	Tridol S6	Ansulite
NZDF Base	Woodbourne	
Sample location	RNZAF Fire Headquarters	RNZAF Fire Headquarters
Collected From	Vehicle R1	IBC
Static/ Movable	Movable	Static
Date Sampled	20/02/2018	
Laboratory Reference	18-74131	
PFBA	<5,000	<5,000
PFBS	<5,000	<5,000
PFPeA	<5,000	<5,000
PFPeS	<5,000	<5,000
PFPPrS	<5,000	<5,000
PFHxA	<5,000	<5,000
PFHpA	<5,000	<5,000
PFHpS	<5,000	<5,000
PFOA	<5,000	<5,000
PFNA	<5,000	<5,000
PFNS	<5,000	<5,000
PFDA	<5,000	<5,000
PFDS	<5,000	<5,000
PFOUnDA	<5,000	<5,000
PFOdoDA	<5,000	<5,000
PFOTrDA	<5,000	<5,000
PFOTeDA	-	-
di-PFHxS (1)	<5,000	<5,000
mono-PFHxS (1)	<5,000	<5,000
L-PFHxS (1)	<5,000	<5,000
Total PFHxS (3) ³	<5,000	<5,000
di-PFOS (5)	<5,000	<5,000
mono-PFOS (5)	<5,000	<5,000
L-PFOS (5)	<5,000	<5,000
Total PFOS (7) ³	<5,000	<5,000
Sum PFHxS+PFOS (1) ⁴	<5,000	<5,000
PFOSA	<5,000	<5,000
NETFOSA-M	<10,000	<10,000
NMeFOSA-M	<50,000	<50,000
NETFOSAA	<5,000	<5,000
NMeFOSAA	<5,000	<5,000
NETFOSE-M	<5,000	<5,000
NMeFOSE-M	<5,000	<5,000
4:2 FTS	<5,000	<5,000
6:2 FTS	<5,000	26,000
8:2 FTS	<5,000	<5,000

- Notes:
1. Values in µg/kg.
 2. Estimated result, the response of which exceeds the calibration range.
 3. Total PFOS, PFHxS are calculated by summing monoethyl, dimethyl and linear isomers. Where an isomer is below the detection limit it is not added to the summation. This is following the method in the reported lab results.
 4. Summations are made by adding compounds Total PFOS (7), Total PFHxS (3) together. Where one compound is below detection, it is not included in the summation.

-	Result not reported by the laboratory
5800	Result is above limit of reporting

Table A-2: Aqueous Film Forming Foam (AFFF) Raw Sample Results - Total Oxidative Precursor Assay (TOPA)

Sample Name	WBN_BLK_003_1_200		WBN_BLK_005_1_200	
Location	WBN_BLK003		WBN_BLK005	
Laboratory Report Number	598344		598344	
Sample Date	22/02/2018		24/02/2018	
Product Name	6% Tridol S6		Ansulite (3%)	
TOPA (Pre/Post)	Pre- TOPA	Post- TOPA	Pre- TOPA	Post- TOPA
Sample Results				
PFBA	< LOR	20,000	480	990,000
PFBS	< LOR	< LOR	< LOR	< LOR
PFPeA	< LOR	36,000	1200	2,120,000
PFPeS	< LOR	< LOR	< LOR	< LOR
PFHxA	42	21,000	4800	1,220,000
PFHpA	< LOR	4,600	240	710,000
PFHpS	< LOR	< LOR	< LOR	< LOR
Total PFHxS	< LOR	< LOR	< LOR	< LOR
Total PFOS	26	< LOR	< LOR	< LOR
Sum PFOS+PFHxS ²	26	< LOR	< LOR	< LOR
PFOA	24	2,200	970	240,000
PFNA	< LOR	1,100	77	180,000
PFDA	< LOR	760	370	77000
PFDS	< LOR	< LOR	< LOR	< LOR
PFTeDA	< LOR	< LOR	34	< LOR
PFTrDA	< LOR	< LOR	< LOR	< LOR
PFUnDA	< LOR	310	27	49000
PFDoDA	< LOR	< LOR	110	21000
4:2 FTSA	< LOR	< LOR	42	< LOR
6:2 FTSA	2,400	< LOR	33,000	< LOR
8:2 FTSA	< LOR	< LOR	4900	< LOR
10:2 FTSA	< LOR	< LOR	1700	< LOR
NETFOSAA	< LOR	< LOR	< LOR	< LOR
NETFOSA	< LOR	< LOR	< LOR	< LOR
NETFOSE	< LOR	< LOR	< LOR	< LOR
NMeFOSAA	< LOR	< LOR	< LOR	< LOR
NMeFOSA	< LOR	< LOR	< LOR	< LOR
NMeFOSE	< LOR	< LOR	< LOR	< LOR
PFOSA	< LOR	< LOR	< LOR	< LOR

Notes.

1. All values in µg/kg (converted from µg/kg assuming all sample material has the same weight).
2. Summations are made by adding compounds Total PFOS (7), Total PFHxS (3) together. Where one compound is below detection, it is not included in the summation.

< LOR Below the Limit of reporting