REPORT

Tonkin+Taylor

Scoping study

Non fire-fighting foam sources of PFAS contamination in New Zealand

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1 Introduction

Tonkin & Taylor Ltd (T+T) has been engaged by Environment Canterbury (ECan) to undertake a scoping study of non- firefighting foam sources of PFAS contamination. This report presents the findings of that scoping study and has been prepared in accordance with our proposal dated 28 March 2018.

1.1 Background

There has been increasing media attention in New Zealand on per and poly-fluoroalkyl substance (PFAS) contamination in groundwater associated with the use of Class B firefighting foams. Facilities which have used foams manufactured using PFAS have been widely identified as those having the greatest potential for significant PFAS contamination owing to the volume in which foams have been used, and the fact that generally, foam runoff has been allowed to discharge to ground.

Consequently, a number of facilities where firefighting foams have historically been used in large quantities are the subject of investigations by the New Zealand Defence Force, Fire and Emergency New Zealand (formerly known as New Zealand Fire Service) and commercial airport operators.

In March 2018, the New Zealand Ministry for the Environment (MfE) issued PFAS guidance[1] to councils which builds upon the PFAS National Environmental Management Plan (PNEMP)[2], developed by the Heads of EPAs Australia and New Zealand (HEPA), released in January 2018. The general approach adopted by the PNEMP and MfE guidance is to:

1. Identify potential PFAS sites;
2. Prioritise sites for investigation; and
3. Investigate sites and assess against risk-based human health and environmental guideline values.

The NEMP and MfE guidance recognise that there are a large number of point and diffuse sources of PFAS other than firefighting foam sites. However, the relative significance of different industries and activities in terms of their relative potential to act as sources of PFAS in New Zealand is not well understood and information is fragmented. There is therefore a need for a reference document that can provide the councils, and the industry more generally, with a starting point from which to identify and prioritise potential non-firefighting foam PFAS sites.

1.2 Objectives and scope

The purpose of this scoping study is to review readily available information regarding non-firefighting foam sources of PFAS to provide a high-level reference document that will:

- Compile available international literature to provide a relative assessment of industries/activities associated with the use of PFAS;
- Assist councils in fulfilling their statutory obligation to identify contaminated sites;
- Provide a starting point/rationale from which to prioritise sites for investigation or identify industries/activities for which more detailed research is warranted; and
- Assist councils in engaging with other stakeholders around the issue of PFAS contamination as it relates to human health risks, environmental effects and effects on cultural values.

T+T has reviewed relevant data available on the internet, supplemented by investigation and other data provided by councils. The review has been time-bound (40 hours of research) and has focussed on collecting the following information (where available) to the extent practicable within this timeframe:

- Identifying non-firefighting foam PFAS sources – i.e. to corroborate or add to those activities/industries identified in the PNEMP/MfE guidance;
- The indicative volumes and concentrations of PFAS substances used in these activities/industries;
- The current and historical prevalence of these activities/industries in NZ, including geographical biases/anomalies;
- Information regarding chemical handling practices associated with these activities/industries in NZ to understand what the general potential for contamination associated with these industries may be; and
- Site/activity/industry-specific monitoring data to develop an understanding of actual contamination associated with these sites.

It should be noted that it is beyond the scope of this assessment to provide a detailed review of PFAS contamination risks associated with particular activities or industries. In addition, the scope of this assessment does not cover:

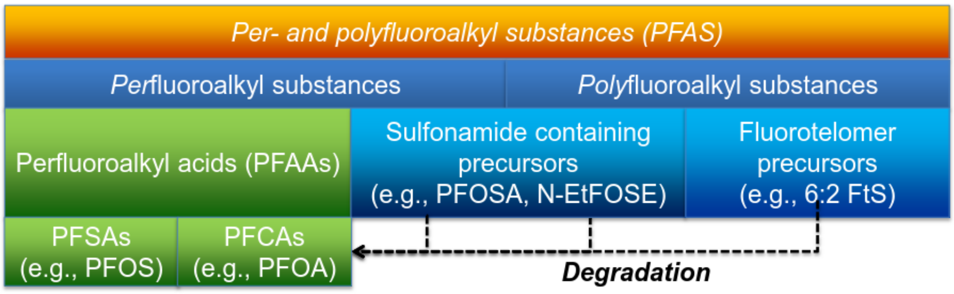
- A detailed assessment of the synthesis or chemistry of PFAS compounds;
- PFAS toxicity;
- PFAS environmental fate and transport; or
- An assessment of the relative significance of point sources against diffuse or ambient sources.

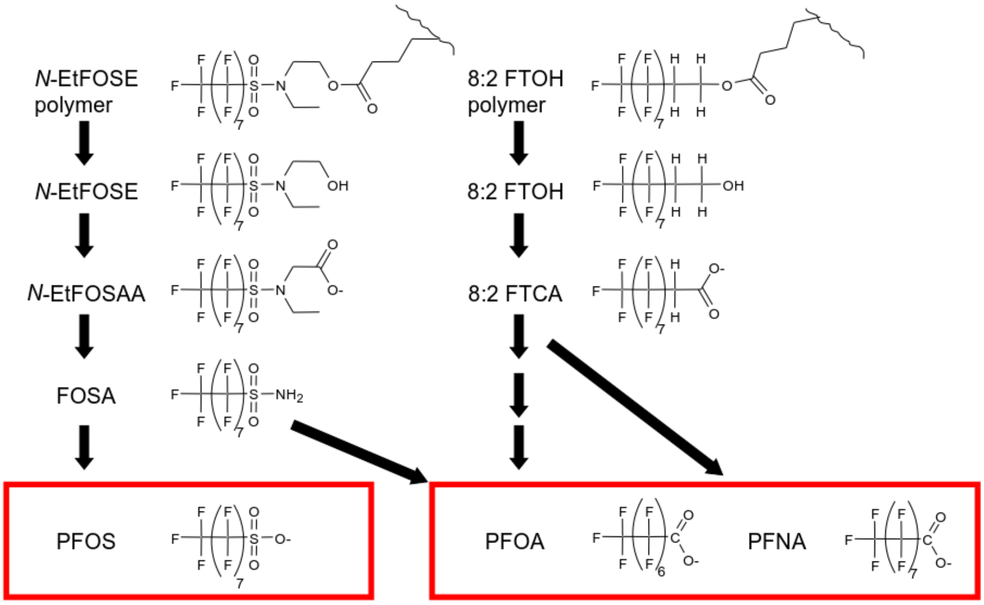
1.3 Terms used in this report

During the course of its research, T+T has identified that terms associated with PFAS have changed over time or are used interchangeably or variably in different research texts. For clarity, Table 1 below provides meanings for a range of important terms which are included in this report.

Table 1 – glossary of key terms used in this report.

Term	Meaning in this report
PFAS	• Per and poly-fluorinated alkyl substances – large family of chemicals containing carbon chain atoms that are at least partially fluorinated and have the generic formulas shown below; • Can be broadly described as either non polymer or polymers; • Non-polymers include: - Perfluoroalkyl sulfonic acids (PFSA) including PFOS and PFHxS (generic formula C_nF_{2n+1}-R); - Perfluoralkyl carboxylic acids (PFCA) including PFOA (generic formula C_nF_{2n+1}-R); and - Fluorotelomers (C_nF_{2n+1}-C_2H_4-R). • Polymers include: - Side chain fluorinated polymers; and - Fluoropolymers.

Term	Meaning in this report
	 *Source: Buck et al 2011*[3]*.*
PFOS, PFOA, PFNA, PFHxS	• Perfluorooctane sulfonate, perfluorohexane sulfonate, perfluorononanoic acid and perfluorooctanoic acid; • These are ‘long chain’ PFAS compounds meaning they contain six or more fully fluorinated carbons (PFSAs) or seven or more fully fluorinated carbons (PFCAs); • These are the PFAS compounds which were generally commercialised for use first and used in a large number of applications until evidence regarding their persistence and toxicity resulted in the introduction of substitutes; and • PFOS, PFOA, PFNA and PFHxS have arguably been the subject of the greatest amount of research. PFOS is listed in Annex B to the Stockholm Convention. PFOA and PFHxS were proposed for listing in 2015 and 2017, respectively.
Side-chain fluorinated polymers	• Fluorinated polymers consisting of non-fluorinated carbon backbones with per or polyfluoroalkyl side chains; • Addition of fluorotelomer as a side chain imparts particular properties to the polymer; and • Fluorinated side chains may be precursors of PFCAs.
Fluoropolymer	• Fluorinated polymers with carbon only backbone with fluorines directly attached to this backbone. Includes PTFE (Teflon®); and • Not made from PFCA or precursors – however, PFCAs may be used as an aid to polymerisation during the manufacturing processes.
Fluorotelomer	• Substances with a carbon chain that is not fully fluorinated; • Includes polyfluorinated fluorotelomer alcohols (FTOHs) which are added as side chains to non-fluorinated compounds; and • These can be broken down into PFCAs in the environment.
Precursor	• In the context of this report, ‘precursor’ means any PFAS compound that could degrade or transform into PFOS, PFOA or PFHxS.

Term	Meaning in this report
	 *Source: Geosyntec Consultants. September 2017*[4].

2 Background to PFAS in New Zealand

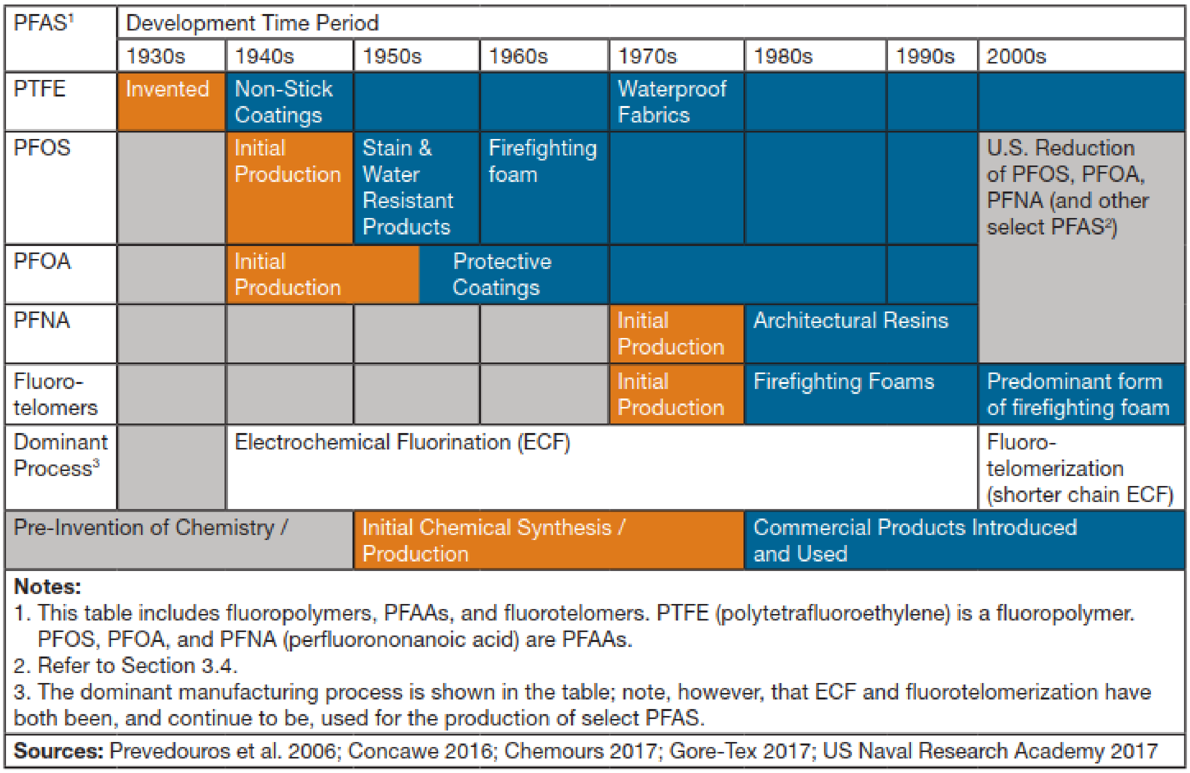
2.1 History of PFAS manufacture and use

PFAS have a number of properties which make them useful including dielectric properties, resistance to heat and chemical degradation and low friction properties. This has led to them being used in a vast range of industrial applications and consumer products.

PFAS were first synthesised in a manufacturing process called electrochemical fluorination (ECF) that was licensed by 3M in the United States in the 1940s. ECF is the only process used to directly produce PFOS and PFOA and was the most important PFAS manufacturing process from the 1950s until 2002 when 3M voluntarily phased out production of long chain products in favour of short chain alternatives.

A second and distinct PFAS manufacturing process is telomerisation which was used by DuPont for the synthesis of the 'carbon backbone' of fluorinated alkyl compounds including polyfluorinated fluorotelomer alcohols (FTOHs). Following the phasing out of the ECF process, telomerisation become the dominant process for the production of long chain PFAS.

PFAS–containing substances were initially commercialised as non-stick coatings, before being incorporated into stain and water resistant substances in the 1950s, fire-fighting foams in the 1960s, and waterproof fabrics in the 1970s. Figure 1 below provides a generalised summary of PFAS manufacture and use.



PFAS[1]	Development Time Period						
	1930s	1940s	1950s	1960s	1970s	1980s	1990s	2000s
PTFE	Invented	Non-Stick Coatings			Waterproof Fabrics			
PFOS		Initial Production	Stain & Water Resistant Products	Firefighting foam				U.S. Reduction of PFOS, PFOA, PFNA (and other select PFAS[2])
PFOA		Initial Production		Protective Coatings				
PFNA					Initial Production	Architectural Resins		
Fluoro-telomers					Initial Production	Firefighting Foams		Predominant form of firefighting foam
Dominant Process[3]		Electrochemical Fluorination (ECF)						Fluoro-telomerization (shorter chain ECF)
Pre-Invention of Chemistry /			Initial Chemical Synthesis / Production			Commercial Products Introduced and Used		

Notes:
1. This table includes fluoropolymers, PFAAs, and fluorotelomers. PTFE (polytetrafluoroethylene) is a fluoropolymer. PFOS, PFOA, and PFNA (perfluorononanoic acid) are PFAAs.
2. Refer to Section 3.4.
3. The dominant manufacturing process is shown in the table; note, however, that ECF and fluorotelomerization have both been, and continue to be, used for the production of select PFAS.

Sources: Prevedouros et al. 2006; Concawe 2016; Chemours 2017; Gore-Tex 2017; US Naval Research Academy 2017

Figure 1: development and use of PFAS. Source – ITRC, 2017[5].

Awareness of the potential environmental and human health effects is thought to have begun in the early 1970s when PFOS was initially detected in the blood of exposed workers in the 1970s, and in the general human population in the 1990s. According to the ITRC[4], PFAS was not widely documented in environmental samples until the early 2000s, potentially due to limitation in analytical accuracy.

As concern grew regarding the toxic, persistent and bioaccumulative nature of the long chained PFAS compounds, regulation was focussed on their manufacture, use and import. In the United States, 3M (principal world manufacturer and sole US manufacturer of PFOS) announced a voluntary phase out of PFOS, PFOA and PFHxS in the early 2000s. In 2006, the United States Environmental Protection Agency (USEPA) initiated a PFOA Stewardship Programme which saw the major manufacturing companies eliminating PFAS and precursor chemical manufacture, however it is noted that imports into the US could still contain these substances. PFOS and related substances were restricted for use in Europe and other jurisdictions (including New Zealand) from 2006.

In 2009, PFOS was added to Annex B of the Stockholm Convention of Persistent Organic Pollutants (POPs) which requires that signatories eliminate production and use of intentionally or unintentionally produced POPs and dispose of POP wastes in an environmentally sound manner. PFOA and PFHxS were proposed for listing in 2015 and 2017, respectively. Figure 2 below presents a timeline for key dates in the manufacture and use of PFAS (note that this is sourced from an American research paper and is largely focused on the history of PFAS from an American perspective).

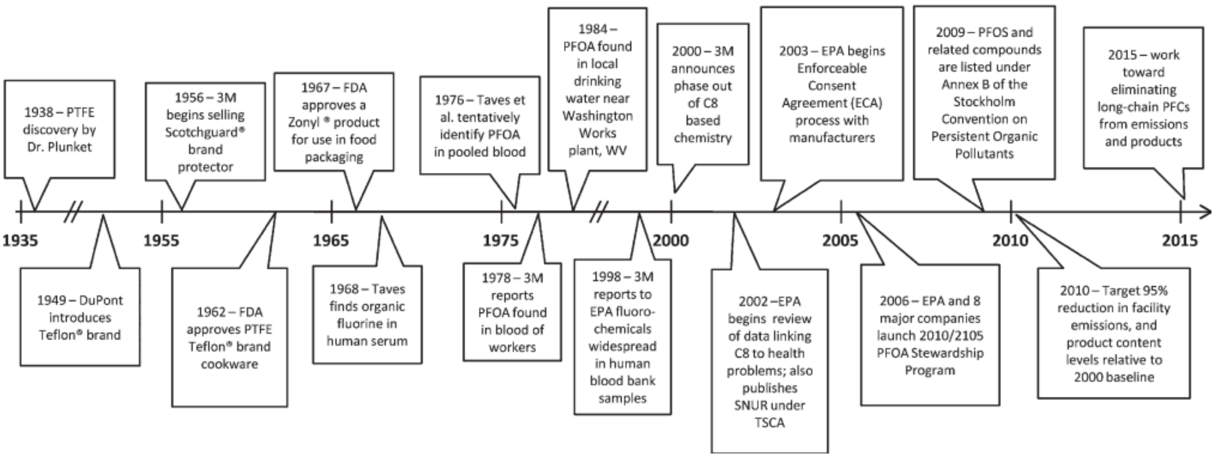


Figure 2. Timeline of PFAS manufacture use and regulation. Source: Lindstrom et al 2011[6].

Manufacturers have continued to develop replacements for long-chain PFAS compounds that use shorter chain perfluoroalkyl or polyfluorinated substances. Although these substances may have shorter half lives in the environment and in the human body, it is inconclusive whether or not some of the alternatives are less toxic than their predecessors.

PFOS is still manufactured globally. As recently as 2016, PFOS and derivatives were being manufactured in Germany, Italy and China[7]. Though the available information is somewhat contradictory, production of PFOS has reportedly been increasing in India and Russia. China is understood to have ratified the Stockholm Convention and would therefore be expected to rapidly reduce production.

From the information available, there is no evidence that PFOS, PFOA or PFHxS were manufactured in New Zealand. However, the potential for the manufacture of intermediate chemicals using PFAS to have been undertaken in New Zealand cannot be discounted.

2.2 Regulatory status in New Zealand

Following the introduction of the Hazardous Substances and New Organisms (HSNO) Act in 1996, regulation of hazardous substances was the responsibility of the Environmental Risk Management Authority (ERMA) until it became the Environmental Protection Authority (EPA) in 2011. The first New Zealand specific controls on PFAS use actually predate the addition of PFOS to the Stockholm

Convention. In 2006, ERMA revised the Fire Fighting Chemicals Group Standard to exclude any substance that is or contains PFOS or PFOA. This reflected voluntary restrictions imposed in Europe and the US at the same time.

New Zealand ratified the Stockholm Convention in 2004. The initial list of 12 POPS covered by the convention did not include PFAS. In December 2006, the MfE published *New Zealand's National Implementation Plan (NIP) under the Stockholm Convention on Persistent Organic Pollutants*. Although published by the MfE, the implementation is the responsibility of a number of New Zealand agencies including the Ministry of Health, ERMA (Now EPA), Ministry for Economic Development (now MBIE) and the New Zealand Customs Service.

The addition of PFOS to Annex B of the convention was completed in a 2009 amendment that was ratified by New Zealand in 2011 through Schedule 2A of the HSNO Act. Since this time no import or use of PFOS compounds is permitted in New Zealand. It is noted that Annex B allows the continued use of PFOS-containing substances for specified uses. These uses are termed in the Stockholm Convention as either 'acceptable purposes' (not time limited) or 'specified exemptions' (cessation by 2016) and include laboratory use, photoimaging, metal plating, aviation hydraulic fluids, insecticides, chemically driven oil production, textiles and upholstery, leather and apparel. According to the EPA[1] New Zealand has not taken up any of the specified exemptions and so any use of PFOS-containing substances in New Zealand would be contrary to the HSNO Act.

As noted above, the New Zealand Stockholm Convention NIP predates the inclusion of PFOS in the convention and therefore requires updating (according to Article 7 of the convention, the revised implementation plan to include PFOS was to be submitted by 2011 - two years following the 2009 amendment). We understand that an updated NIP will be available in late 2018.

In 2017, Food Standards Australia and New Zealand proposed health based guidance values for PFOS, PFOA and PFHxS. The New Zealand Ministry of Health subsequently accepted the Australian drinking water quality guideline for PFOS, PFOA and PFHxS as interim guidance levels. Whilst these guidelines do not directly regulate use, they do indicate that regulation in New Zealand remains largely focussed on long-chained PFAS compounds.

As discussed in Section 1.1, in January 2018, HEPA issued the PNEMP. The PNEMP includes health and environmental guidelines for soil, freshwater and marine water. The PNEMP also provides guidance regarding the prioritisation of site investigations, investigation and sampling techniques, site treatment and remediation and communication and engagement.

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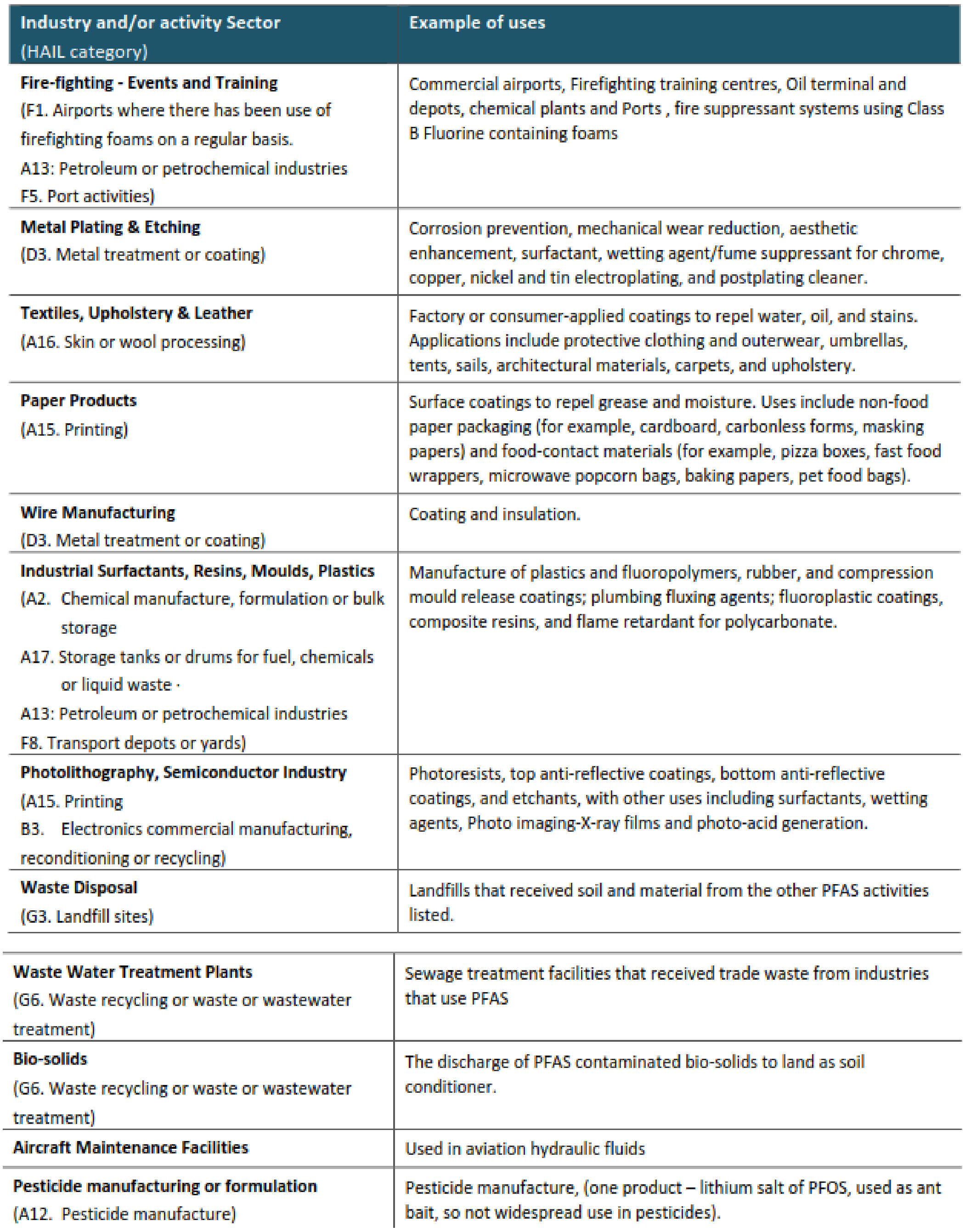
[1] Personal communication (by email) with Peter Dawson, 27 April 2018.

3 Review of potential PFAS sources

3.1 General approach

One of the principal objectives of this scoping study is to assist councils in identifying sites where PFAS may be a contaminant of concern and prioritise sites for investigation. T+T has therefore focussed on reviewing available information for those industries and activities contained within the list of potential sources of PFAS releases summarised in Table 1 of the March 2018 MfE Advice to Councils[1].



Industry and/or activity Sector (HAIL category)	Example of uses
Fire-fighting - Events and Training (F1. Airports where there has been use of firefighting foams on a regular basis. A13: Petroleum or petrochemical industries F5. Port activities)	Commercial airports, Firefighting training centres, Oil terminal and depots, chemical plants and Ports , fire suppressant systems using Class B Fluorine containing foams
Metal Plating & Etching (D3. Metal treatment or coating)	Corrosion prevention, mechanical wear reduction, aesthetic enhancement, surfactant, wetting agent/fume suppressant for chrome, copper, nickel and tin electroplating, and postplating cleaner.
Textiles, Upholstery & Leather (A16. Skin or wool processing)	Factory or consumer-applied coatings to repel water, oil, and stains. Applications include protective clothing and outerwear, umbrellas, tents, sails, architectural materials, carpets, and upholstery.
Paper Products (A15. Printing)	Surface coatings to repel grease and moisture. Uses include non-food paper packaging (for example, cardboard, carbonless forms, masking papers) and food-contact materials (for example, pizza boxes, fast food wrappers, microwave popcorn bags, baking papers, pet food bags).
Wire Manufacturing (D3. Metal treatment or coating)	Coating and insulation.
Industrial Surfactants, Resins, Moulds, Plastics (A2. Chemical manufacture, formulation or bulk storage A17. Storage tanks or drums for fuel, chemicals or liquid waste · A13: Petroleum or petrochemical industries F8. Transport depots or yards)	Manufacture of plastics and fluoropolymers, rubber, and compression mould release coatings; plumbing fluxing agents; fluoroplastic coatings, composite resins, and flame retardant for polycarbonate.
Photolithography, Semiconductor Industry (A15. Printing B3. Electronics commercial manufacturing, reconditioning or recycling)	Photoresists, top anti-reflective coatings, bottom anti-reflective coatings, and etchants, with other uses including surfactants, wetting agents, Photo imaging-X-ray films and photo-acid generation.
Waste Disposal (G3. Landfill sites)	Landfills that received soil and material from the other PFAS activities listed.
Waste Water Treatment Plants (G6. Waste recycling or waste or wastewater treatment)	Sewage treatment facilities that received trade waste from industries that use PFAS
Bio-solids (G6. Waste recycling or waste or wastewater treatment)	The discharge of PFAS contaminated bio-solids to land as soil conditioner.
Aircraft Maintenance Facilities	Used in aviation hydraulic fluids
Pesticide manufacturing or formulation (A12. Pesticide manufacture)	Pesticide manufacture, (one product – lithium salt of PFOS, used as ant bait, so not widespread use in pesticides).

Figure 3: List of potential sources of PFAS releases to the New Zealand Environment based on manufacturing and other sectors. MfE (2018)[1].

Sections 3.2-3.12 below present a summary of the information reviewed together with a qualitative assessment of the potential for that activity/industry to be associated with PFAS contamination. It should be noted that due to time constraints and the data available, this assessment is subjective and based on the professional judgement of the author.

3.2 Metal plating and etching

Activity	Metal plating and etching. Includes: HAIL D3 – metal treatment or coating.
PFAS use details	Non-polymeric PFASs (e.g. PFOS, fluorotelomers) are used as surfactants, wetting agents and misting suppressants[8]. Principally, they are used to reduce the generation of Cr(VI) aerosols during chrome plating by reducing surface tension on the surface of the plating solution. For plating applications, PFAS are typically added to the plating bath when necessary (i.e. when increased aerosol formation is observed). Additional mist suppressant is added to the bath periodically as PFOS is degraded in the bath, depending on the electrical charge used. The plating bath solution is disposed when contaminated (i.e. no longer useable for plating) and may contain residual PFOS/PFAS. Trade names of wetting agents currently used internationally and which may contain PFOS (including NZ) include "Fumetrol" and "zero Mist", but non PFOS-containing mist suppressants are also currently used. A Danish study[9] indicates that the concentration of PFOS in mist suppressants can be in the range of 1-15% depending on the formulation. PFOS may be used in a concentration range of 30-80 mg/L in the plating solution[10]. No information was available regarding the amount of PFOS used in NZ, but as an indication the same Danish study references sources indicating the following usage for chrome plating in various countries in 2008/2009 (as pure PFOS): Denmark 10-28 kg/year; Australia 1,070 kg/year; UK 120-135 kg/year. Data[11] indicates that chrome plating is by an order of magnitude the largest users of PFOS of those applications that are exempted under the Stockholm Convention.
Period of use	It is assumed that PFOS-containing products have been commercially available in NZ from 1950s, in line with their general global availability. Lawful use of PFOS-containing substances ceased in 2011, though it is possible that use continued after this date as stocks were used up. PFAS containing substitutes (e.g. 6:2 FtS) are likely to be in current use.
Location of activities	There are a large number of currently operating plating facilities of variable size in New Zealand. Most urban areas are likely to contain plating facilities. There is no evidence to indicate that historically, the number and distribution of plating facilities in New Zealand would have been significantly different to current.
Potential contamination mechanisms	The potential for discharges from a particular facility will be dependent on the handling practices of that facility. However, in general terms, it is likely that the principal source of PFOS contamination at plating facilities will be through the loss/spillage of plating bath effluent – either directly as spillages in processing areas or indirectly as effluent is discharged through effluent systems. The mobility of PFAS in the environment and the potential for PFAS substances to move beyond containment structures is likely to be increased through the use of corrosive plating substances. Direct spillage of undiluted wetting agents is also a plausible source.
Investigation/monitoring data	A large amount of international monitoring data has identified detectable PFAS contamination in soil, groundwater, and surface water near electroplating facilities and indicates that PFOS and PFOA can be present in groundwater above NZ MoH guideline levels[12]. Recent investigations[13] in New Zealand detected well above NZ MoH Drinking water Guidelines and above freshwater and marine guideline values for ecological protection. The specific contaminant discharge route(s) from these facilities is uncertain, though most

	likely to be via the inappropriate disposal of plating wastes and/or poorly maintained effluent systems. In addition USEPA data[14] indicates that as PFAS concentrations in plating facility effluent can be highly elevated, effluent discharge from plating facilities to waste water treatment plants can be a significant contributor to PFAS in wastewater treatment plant influent
Significance as source	The potential for PFAS contamination from chrome plating facilities will vary considerably from site to site due to the scale and operating practices. Chrome plating facilities are considered to have a high potential as sources for environmental PFAS contamination for the following reasons: • Although the scale, substance use and management of a particular site will vary, plating facilities may have created (and may continue to create) moderate volumes of PFAS-containing effluent over their lifetime; • Plating processes use corrosive substances which can increase the mobility of PFAS in the environment and can reduce the effectiveness of containment structures and integrity of effluent systems; and • NZ and international data has shown that PFAS can be detected in soil and groundwater above current NZ MoH guideline levels near plating facilities. Similarly, plating bath effluents have also been shown to contain high concentrations of PFAS. Inappropriate handling and disposal of effluents represents a potentially significant source of PFAS contamination.
Further work	Obtain data regarding typical substances used in mist suppression, historical volumes used and effluent volumes produced in NZ. Collate data on other site specific investigations in NZ (if any).

3.3 Textiles, upholstery & leather

Activity	Textiles, upholstery and leather. Includes: HAIL A16 – Skin or wool processing.
PFAS use details	The textile industry has used PFAS to achieve water, oil and dirt repellence in fabrics. PFAS polymers are also used in the manufacture of flame retardant clothing. A 2015 Danish study[15] suggested that the textile industry accounts for approximately 50% by weight of the global use of PFAS, whilst data on global PFOS usage compiled by the 3M company in 2000 indicated that the volume of PFOS used in the textiles industry was equal to that for all other uses combined[16]. Available information indicates that use is associated with either (i) the formulation of polymerised textile finishes or fabrics (such as Gore-Tex) in which PFOS may be present as contamination or created due to the degradation of precursors; or (ii) the 'active' ingredient in fabric treatments applied either during manufacture or after-market (e.g. 'Scotchgard'). The difference between these uses is potentially significant in terms of the potential for contamination as generally smaller volumes of non-polymer PFAS would be used in the production of polymers than were used as surface treatments. Even so, the content of PFOS in polymerised treatment products has been estimated at up to 2% by weight[17]. With respect to application rates, UNEP[18] estimates that the PFOS derivatives were present at 2-3% of fibre weight for textiles but 15% of fibre weight for carpets. No evidence has been sighted as part of this project to indicate that Gore-Tex or similar fabrics have been manufactured in New Zealand – rather fabrics are more likely to have been imported into New Zealand for manufacture into finished goods. However, It is possible that PFAS substances have been used in the manufacture of leather goods in New Zealand – including footwear. For carpets, PFAS can be applied during the manufacturing process at the carpet mill (using predominantly solvent- based chemicals) or applied following manufacturing to a finished product (typically as a water based spray or solution). It should be noted that PFAS use on carpets only relates to synthetic products and not wool carpets. Brands of stain resistance carpets include Stainmaster (DuPont), Wear-Dated (Monsanto) and Worry-Free (Allied Signal). Stainmaster-branded carpets were historically manufactured in New Zealand by Feltex. It has not been possible to obtain information regarding the typical volumes of storage and use. However, given the large surface area of the products it is likely that the volumes of stain repellents used could be very large – particularly at carpet mills.
Period of use	One source[19] contends that expanded polytetrafluorethylene (ePTFE – forerunner of Gore-Tex) was actually invented in New Zealand by John W Cropper in 1966 when he was approached by DuPont to manufacture a machine for producing Teflon tape. The US-based WL Gore Company developed a similar process in 1969, largely as Cropper had not patented his process. WL Gore commercialised Gore-Tex production in the early 1970s. Manufacturing of carpets using PFOS-containing surface treatments commenced in the mid-1980s until officially banned in NZ in 2011 – though replacement products may contain PFOS or PFOA precursors. PFOS containing stain repellents were manufactured as an after-market treatment in the USA from the mid-1960s. PFOS was reportedly removed from Scotchgard by 3M in 2000.
Location of activities	Textile and carpet production is and has been widespread in New Zealand, though the extent of PFAS use in the manufacturing process is not known. Carpet manufacturing firms are currently operating in Hamilton and Auckland. Plants were formerly present in Foxton,

	Fielding, Wainuiomata and Christchurch. Numerous specialist clothing manufacturers are located in NZ, though it is not known if stain repellent application would be undertaken at these plants, or at an earlier stage of the manufacturing process. PFAS may also have been used in the manufacture of leather goods, which similarly has occurred widely throughout New Zealand.
Potential contamination mechanisms	As with other manufacturing facilities, the principal discharge routes are via loss of stored chemicals and wastes to ground, discharge of effluents, and atmospheric losses. Disposal of PFAS containing solid and liquid waste may contribute to diffuse sources from landfills.
Investigation/monitoring data	Research conducted for this scoping study did not identify any investigation or monitoring data regarding PFAS soil or groundwater contamination associated specifically with textile manufacture in New Zealand. However, a dataset compiled by Northeastern University[20] in the US includes several references to site investigation data where elevated PFAS concentrations in drinking water, soil or sediment have been attributed to textiles or tannery facilities.
Significance as source	Textile manufacturing facilities are considered to have a moderate to high potential to act as a point source of environmental PFAS contamination for the following reasons: • Depending on the specific manufacturing processes involved, potentially large volumes of PFAS-containing chemicals may have been used in the production of textiles and finished goods. This is particularly true of carpet manufacture; and • International research indicates that elevated PFAS concentrations in environmental media can be attributed to direct discharges from textile plants – particularly in the form of liquid effluent.
Further work	Clarify specific typical/range of volumes used, application processes and effluent management. Obtain site specific assessment data, if available.

3.4 Paper Products

Activity	Paper products. Includes A15 – printing.
PFAS use details	Fluorinated surfactants have been used for paper uses since the early 1960s[21] to manufacture grease and water-repellent paper. A content of 1-1.5% by weight of the paper product is typical[18]. PFOS derivatives have been used both in food contact applications such as plates, food containers, popcorn bags, pizza boxes and wraps and in non-food contact applications such as folding cartons, containers and masking paper. Before 2000 approximately 32% of the total use of PFOS in the European Union was for paper coating[18]. Since the withdrawal of PFOS derivatives, alternative PFAS-related paper additives have included short chain telomers and perfluoropolyesters. As of 2013, the UNEP stated that paper products was the third largest category of fluorotelomer use[21]. Various methods of application are used including (i) addition through the wet end press where the surfactants are mixed with paper fibres before entering the forming table; and (ii) application at the size press and film press stages in which the paper is impregnated with a surfactant. It is also important to note that paper plants that process recycled paper (which may itself contain PFAS) may also be potential sources of PFAS contamination.
Period of use	Based on global use, use in NZ may have commenced in the 1960s. PFAS precursors (telomers) are likely to remain in use, though non-fluorinated products are available.
Location of activities	Pulp and paper mills are or have been present in: Mataura, Whakatane, Te Papapa, Kariori, Napier, Kinleith, Kawerau.
Potential contamination mechanisms	Release of PFAS-containing solutions dues to spills, loss to atmosphere during drying. As conventional effluent treatment systems may not be effective in removing PFAS, paper mill effluent discharge and land application of biosolids are considered potential sources of environmental PFAS.
Investigation/monitoring data	This study has identified limited monitoring data specifically related to potential environmental discharges of PFAS from paper and pulp mills. Monitoring of surface waters in Michigan, US downstream of paper mill effluent discharges[22] detected PFOS and PFOA approximately 2-3 orders of magnitude below NZ MoH drinking water guidelines and 1-2 orders of magnitude below the most conservative ANZECC freshwater criteria. An investigation led by the Department of Environmental Conservation and Department of Health in New York State, US identified elevated concentrations of PFOS and PFOA within sludge derived from paper mills in the State[23].
Significance as source	Due to the volume of PFAS which can be used in paper manufacture, paper and pulp manufacturing facilities are considered to have a high potential to act as sources of PFAS contamination.
Further work	Obtain further site specific monitoring data. Confirm use of PFAS products in NZ paper plants.

3.5 Wire Manufacture

Activity	Industrial surfactants, resins, moulds, plastics. Includes: HAIL D3 – metal treatment or coating.
PFAS use details	Wire manufacturing is one of largest segments for fluoropolymer use in the US accounting for over 50% of fluoropolymer production[24]. PTFE is possibly the most widely used fluoropolymer. May contain PFOA carried through from manufacturing of PTFE. Available information indicates that wire manufacture uses PTFE powder or granules which are extruded onto wire under high pressure. The wire is then 'cured' using heat. This curing process drives off volatile compounds, potentially including PFOA or precursors. However, it is also noted that some PTFE products including hoses can be manufactured using a 'paste extrusion' process, whereby PTFE is mixed with a 'lubricant' to assist in extrusion. This lubricant is required to have a lower boiling point than the PTFE and is driven off during the drying process and can include gasoline[25].
Period of use	1970s onwards – PTFE used to present day.
Location of activities	Historically numerous facilities in NZ including closed facilities. An operational cable manufacturing facility is located in New Plymouth.
Potential contamination mechanisms	Limited – available data indicates that PTFE material is supplied to manufacturer in solid form. The potential for contamination through spillage would therefore seem low. If washing occurs during the manufacturing process, low concentrations of PFAS may enter effluent stream. Volatile PFAS may be discharged to air during curing process.
Investigation/monitoring data	None identified.
Significance as source	Low given likely low concentration of PFAS used, plus solid nature of process feedstock makes contamination through spillage unlikely. Uncertainty regarding potential for atmospheric discharge.
Further work	Clarify manufacturing process and NZ use.

3.6 Industrial surfactants, resins, moulds, plastics

Activity	Industrial surfactants, resins, moulds, plastics. Includes: HAIL A2- chemical manufacture, formulation or bulk storage, HAIL A17-Storage tanks or drums for fuel, chemicals or liquid waste, HAIL A13 – Petroleum or petrochemical industries, HAIL F8 – Transport depots or yards.
PFAS use details	PFAS containing chemicals are used in a vast range of industrial applications including[26]: • Industrial cleaners, including metals parts post nickel plating; • Paints, inks and varnishes, including anti-floating agents for pigments and as an additive in corrosion resistant paints; • The manufacture of PTFE and polyvinylidine fluoride (PVDF). PTFE applications have been discussed above. PVDF applications include chemical handling equipment; • PFAS are used as mold-release agents for thermoplastics, polypropylene, epoxy resins and polyurethane foam moulding; • Also used in solvent and water-based adhesives to improve contact between joining surfaces; • Applied to glass, metal or plastic as an anti-mist film; and • An intermediary or synthesis chemical in the production of fluoropolymers – though it is considered unlikely that this process was undertaken in New Zealand. Due to the range of potential applications the volumes and concentrations of substances used cannot be estimated. However, other than for fluoropolymer synthesis it is likely that relatively small volumes and low concentrations have been used in New Zealand in comparison to other potential sources.
Period of use	Unknown, though use of precursor products is almost certainly occurring in New Zealand.
Location of activities	Assumed to be widespread due to the range of potential applications.
Potential contamination mechanisms	Spillage of process chemicals or chemical wastes, atmospheric discharge during drying process, discharge of effluent. Atmospheric deposition on PFAS has also been identified at plants where PFAS treated plastics have been dried during manufacture. It is possible that the use of chemicals in outdoor applications (e.g. industrial cleaning solutions) has resulted in low-level releases.
Investigation/monitoring data	None identified.
Significance as source	Due to the potential range of applications, volumes and concentrations used and stored the use of PFAS-containing industrial chemicals as a source of contamination is uncertain.
Further work	Clarify NZ industrial and manufacturing processes that may have used PFAS substances (likely to be numerous).

3.7 Photolithography, Semiconductor Industry

Activity	Photolithography, Semiconductor Industry. Includes: HAIL A15 – Printing, B3 – Electronics commercial manufacturing, reconditioning or recycling.
PFAS use details	PFAS substances, including PFOA have been used for a range of highly specialised commercial applications within the electronics and semiconductor industries. PFOA has been used in the etching of circuit lines on wafer-thin chips where anti-reflective coatings were required[27]. Fluoropolymers are also used to manufacture components in the semiconductor industry that are used to handle corrosive liquids and gases and where high material purity is required[28]. One study[29] reports that PFOA concentrations of 0.02% to 0.1% were typically used in the semiconductor industry. According to UNEP 2011[18], PFOS-based chemicals have (and may continue to be) used in the manufacture of everyday consumer electronics products such as phones, printers, computers etc. The same study reports that PFOS has been present in the intermediate transfer belt of printers at a concentration of 100 ppm. PFAS, including PFOS has been used in manufacturing photographic film, paper and plates. Film, paper and plate production and use has declined significantly since the advent of digital photography. Even so, according to a 2006 OECD survey[30], up to 20 tonnes of lithium perfluorooctane sulfonate were used annually as anti-reflective agents in the photographic industry. The data reviewed does not allow an estimate of the likely volume of PFAS used in these applications to be made, let alone the likely volume of use in New Zealand. However, a 2004 dossier[31] indicates that in 2004, the UK demand for PFOS by the photographic and photolithographic industries was approximately the same as the metal plating industry.
Period of use	No data has been reviewed that clearly identifies the likely interval of use. However, for electronics and semiconductors it could be inferred that globally, the use of these substances coincided with the development of micro-electronics (i.e. from the 1970s onwards). It is unclear when use of the substances for photographic applications may have commenced. Although the uses of PFOS – containing substances has been banned in NZ since 2011, use may have continued whilst stocks were used. Non-PFAS substitutes have been available in some applications for a considerable time, so it is possible that some individual operators in this industry have never used PFAS-containing substances.
Location of activities	Potentially widespread though likely to be confined to major centres.
Potential contamination mechanisms	Given the generally highly controlled nature of the manufacturing process associated with these industries, which relies on material purity and therefore isolation from the wider environment, the risk of contamination occurring as a result of leaks or spills is considered low. However, data does suggest that wastewater discharges from these facilities could be a significant source, presumably where materials handling is poor. Since these substances have been banned in NZ and non-fluorinated substitutes have become available, the potential for discharge via wastewater is likely to have reduced significantly.
Investigation/monitoring data	There is limited data available which directly relates PFAS concentrations in environmental media to the electronics or semi-conductor industries. A study from Taiwan[32] monitored wastewater discharges into and surface water concentrations of PFAS in three Taiwanese

	Rivers downstream of electronics plants and found PFOS in wastewater at concentrations of up to 0.13 mg/l, and PFOS in river water samples at up to 5.4 ug/L.
Significance as source	Due to the controls placed on PFOS under the HSNO act and Stockholm convention, the likelihood of use of PFOS since 2011 is low. However, the use of other PFAS, including precursors is uncertain. Historically, on the assumption that the scale of the electronics and photographic industry in NZ is and has been relatively small by international standards, and the process utilising PFAS relatively well controlled, the potential for PFAS to be a significant contaminant of concern at these sites in NZ is considered low relative to other sectors assessed in this study.
Further work	Obtain NZ specific data on the use of PFAS in the electronics, photolithographic and photographic industries – particularly the use of non-PFOS fluorinated alternatives.

3.8 Waste Disposal

Activity	Waste disposal. Includes: HAIL G3 – landfill sites.
PFAS use details	PFAS contamination within landfills is generally associated with the formation of PFAS-containing leachate derived from PFAS containing- waste. The waste sources could include consumer products (for example treated textiles, paper products), waste industrial chemicals, waste from treatment plants and potentially landfill fires (use of AFFF).
Period of use	In the absence of evidence to the contrary, it would be reasonable to assume that any landfill operating in the period of PFAS use (i.e. from 1940s onwards) could generate PFAS-containing leachate.
Location of activities	Nation-wide.
Potential contamination mechanisms	Leaching of PFAS compounds into leachate. Direct discharge of leachate into groundwater and/or surface water.
Investigation/monitoring data	Internationally, there is a large amount of data on the presence of PFAS compounds in landfill leachate. Average concentrations of PFOA in leachate samples from 20 landfills in the US was approximately 0.8 ug/l[33]. US monitoring indicates that degradation of PFAA-precursors and changes in leachate pH, EC, and 24-h precipitation were important factors controlling PFAS occurrence in leachate[34]. A study of landfill leachate from landfills in northern Spain[35] stated that PFAS was ubiquitous in both raw and treated leachate, with data from 6 landfill sites showing total PFAS concentrations in the range 0.6 to 3.2 ug/L. A Swedish study[36] of PFAS concentrations in leachate, groundwater, treatment plant sludge and surface water at a single landfill identified PFAS concentrations of up to 1.6 ug/L in leachate. ALS Environmental[37] completed a small investigation of PFAS concentrations in leachate from five Australian landfills and found that median PFOS and PFOA concentrations were 0.23 and 0.44 ug/L, respectively. Median concentrations of 6:2 FTS were considerably higher at 9.25ug/L. PFAS detected in an adjacent river which receives effluent (treated leachate) from the landfill were detected at a maximum of 0.041 ug/L. An Australian study[38] identified PFHxA as the predominant PFAS compound in leachate with concentrations of up to 25 ug/L. Studies completed in the US suggest that leachate impact on groundwater supplies have been relatively limited[39]. This is somewhat supported by specific studies by the Department of Environmental Services in New Hampshire[40] which shows that less than 2% of drinking groundwater samples collected from wells near landfills contained PFAS concentrations above the 0.07 ug/L New Hampshire State drinking water limit. There are, however well documented examples of public water supplies containing PFAS above permissible limits – including the case of Oakdale, US where PFOS and PFOA have been detected at up to 1.5 ug/L and 1.0ug/L, respectively[41]. It is likely that as awareness of the potential for PFAS in landfill leachate increases, monitoring of public water supplies for PFAS will similarly increase. Evidence of landfill-sourced PFAS contamination of public water supplies is available, and it would seem that regulators in some jurisdictions are adopting a precautionary stance by offering alternative water supplies even where PFAS concentrations are below allowable limits. An example of this is Kent County in New England where PFOS concentrations in the range 50 - 60 ppt have been detected (with the EPA limit being 70 ppt/ 0.07 ug/L).

Significance as source	Landfills are considered to have a high potential to act as sources of PFAS on the basis that: • A large amount of international data is available which indicates that PFAS can be present at high concentrations in landfill leachate; • Leachate treatment systems can be ineffective at removing PFAS compounds; • A large number of closed landfills in NZ are unlined, with the potential for leachate to discharge to groundwater; • Landfills can act as a long-term source; and • Concentrations can fluctuate over time and across different landfills due to waste composition and environmental factors.
Further work	Obtain NZ-specific data for PFAS concentrations in landfill leachate and environmental media near landfills. Complete risk assessment to identify proximity of landfills to sensitive receptors.

3.9 Waste Water Treatment Plants

Activity	Wastewater treatment plants (WWTPs). Includes: HAIL G6 – Waste recycling or waste or wastewater treatment.
PFAS use details	PFAS compounds are received in the form of industrial and domestic effluent discharges.
Period of use	WWTPs are likely to have received PFAS containing effluent for as long as manufacturing processes that have used PFAS compounds and use of PFAS-containing consumer products have occurred in New Zealand.
Location of activities	Nationwide, though PFAS inputs would be expected to be higher for WWTPs servicing urban areas and with industrial inputs when compared to rural WWTPs.
Potential contamination mechanisms	Discharge of treated effluent. Discharge of biosolids (sludge). Discharges to air from aeration tanks.
Investigation/monitoring data	WWTPs are a potential source of PFAS in surface water as common treatment processes generally do not significantly reduce total PFAS concentrations in effluent compared to influent. There is evidence that concentrations of stable PFAS compounds in effluent can be higher than in the plant influent due to biotransformation of precursors in the treatment process. However, data regarding what might be considered 'typical' concentrations of PFOS and PFOA in effluent indicates that generally, effluent concentrations from municipal WWTPs do not exceed NZ drinking water or freshwater guidelines. • Concentrations of PFOS and PFOA detected in effluent from three WWTPs in Sweden[42] were at least one order of magnitude below NZ drinking water guidelines and two orders of magnitude below NZ freshwater guidelines. Similar levels of PFOS and PFOA were detected in a study undertaken by Uppsala University[43]; • Whilst 'total' PFAS concentrations in wastewater may exceed 500 ng/L/ (PPT), data presented by Hamid[44] indicates that PFOS and PFOA concentrations in WWTP plant effluent in Denmark, Spain, Greece, Sweden and Canada are also well below NZ drinking water and freshwater guidelines; • PFOA concentrations in effluent from an Athens treatment plant exceed the NZ drinking water guidelines (but were still well below freshwater guidelines); • Mean concentrations of PFOS and PFOA in the effluent of two Greek WWTPs[45] were less than 20 ng/L (PPT) compared to a NZ drinking water guideline of 70 and 560 ng/L respectively; and • A review of global WWTP effluent data by Arvanti *et al* in 2015[46] indicated that C8-range PFCs were detected at concentrations of up to ~ 180 ng/L in North America, 468 ng/L in Europe, and 1000 ng/L in Asia. The study also comments on specific effluent data from one plant in Australia where PFOS and PFOA were detected at concentrations of 39 ng/L and 27 ng/L respectively – again well below current NZ drinking water and freshwater guidelines. Despite what appear to be generally low concentrations of PFOS and PFOA in WWTP effluent, significantly higher effluent concentrations are likely where a WWTP receives industrial effluent. There is some evidence that authorities in the US are requiring WWTP operators to identify which of its industrial customers use PFAS. This comes after PFAS concentrations of up to 2 ug/L were

	detected in treated effluent discharged from the Lapeer WWTP in Lapeer, Michigan, having received plating effluent with PFAS concentrations of 12-19 ug/L[47]. In addition, whilst the above studies report on individual PFOS and PFOA concentrations, all also acknowledge the high concentrations of precursors compounds in WWTP liquid effluent and the potential for these to degrade to more persistent and toxic compounds. By focussing on detectible PFOS and PFOA concentrations in effluent, the potential for PFOS and PFOA to be created through degradation of precursors may be underestimated. There is also evidence to indicate the WWTPs may be point sources for airborne PFAS discharges. Monitoring indicates that airborne PFAS concentrations above WWTPs can be 1-15 times higher than reference sites[37]. According to Hamid (2016)[44], few studies have investigated the fate of PFAS through the conventional and/or advance WWTP treatment train. Primary treatment that focusses on settling of solids appears to result in very little PFAS removal. In some cases, secondary biological treatment has been found to increase effluent concentrations of PFOS and PFOA due in particular to the biodegradation of fluorotelomer alcohols.
Significance as source	The available data indicate that WWTPs are point sources of PFAS discharge in liquid effluent. Whilst the data indicate that PFOS and PFOA in liquid effluent are generally below NZ drinking water and freshwater guidelines, concentrations will depend on the nature/source of WWTP influent and the nature of the treatment processes employed. Also, WWTPs appear to concentrate PFAS compounds in liquid effluent, with higher concentrations of precursor compounds typically detected in effluent compared to influent. Therefore although PFOS and PFOA concentrations discharged in WWTP effluent may not themselves exceed NZ guideline values, WWTP effluent represents a source of future PFOS and PFOA due to the subsequent environmental degradation of precursors. Furthermore, as discharge from WWTPS may be near continuous, although discharge concentrations may comply with relevant guidelines, the mass flux of PFAS in WWTP discharge is likely to place WWTPs as one of the most significant point sources of PFAS.
Further work	Obtain New Zealand-specific monitoring data for WWTP effluent and receiving environments. Understand nature of treatment processes employed in New Zealand and identify potential implications for PFAS removal based in international research.

3.10 Biosolids

Activity	Biosolids. Includes: HAIL G6 – Waste recycling or waste or wastewater treatment.
PFAS use details	PFAS disposed to land as a contaminant during biosolids application. This includes the application of treated sewage sludge, animal effluent and industrial biosolids (e.g. paper and pulp waste).
Period of use	Based upon the 1975 Department of Health publication *Disposal of sewage effluent and sewage sludge on land*, biosolids (sewage sludge) application has taken place in NZ since at least the 1970s.
Location of activities	Nationwide.
Potential contamination mechanisms	Leaching of PFAS from sludge to soil, groundwater or surface water due to infiltrating rainfall or drainage of liquid component. Incorporation of PFAS-containing sludge into soil.
Investigation/monitoring data	Based on a study of WWTPs in Hong Kong, Ma and Shih[48] argue that WWTPs are a net sink for PFAS noting that the majority of the PFAS mass exiting the WWTPs were bound into sludge rather than liquid effluent. A 2013 US study[49], in which samples collected as part of the 2001 National Sewage Sludge Survey were analysed for PFAS detected PFOS at an average concentration of 400 ug/kg. By comparison, concentrations of PFOS in sludge samples collected from 15 wastewater treatment plants in Spain and Germany[50] were an order of magnitude lower (average 5 ug/kg in Spanish samples, 39 ug/kg in German samples). It is possible that the difference in magnitude could be accounted for by both differences in the influent source (potentially a higher proportion of industrial inputs in the US samples) and the sampling period (the use and therefore discharge of PFOS is likely to have declined between the two sampling periods (2001 vs 2012). Gallen *et al* (2016)[51] studied PFAS concentrations in biosolids at a variety of Australian wastewater treatment plants and identified concentrations of PFOS in the range 11-370 ug/kg, with the upper end of the range similar to that reported for the analysis of US, German and Spanish samples as discussed above. The type of biosolids (liquid vs dewatered) can reportedly have an effect in the leaching of PFAS compounds[52]. Gottschall *et al* (2010)[53] compared the leaching of PFAS into tile drains from the surface application of Liquid Municipal Biosolids (LMB) and Dewatered Municipal Biosolids (DMB). PFOS was detected at a maximum concentration of 17 ng/l and PFOA at 12ng/L in tile drainage from the application plots. There are examples where the application of industrially-derived biosolids are believed to have had a direct impact on groundwater, possibly the most well-known example being that of Decateur in Alabama where a municipal treatment facility had received PFAS-containing effluent from 3M manufacturing facility. Biosolids from the treatment plant were applied as a soil treatment to fields over at least a 10 year period. PFAS impacts in local groundwater supplies were subsequently identified and a no-drink order placed on groundwater serving over 100,000 people. However, the potential for biosolids application derived from non-industrial treatment facilities or from municipal facilities without significant industrial inputs to result in PFAS levels in drinking water above guideline

	values is unclear[54] and is likely to be very site specific with major factors being climate, soil composition, application rate and hydrogeology. Considerable research has been conducted into PFAS bioavailability and plant uptake in soils amended by PFAS –containing biosolids. There is widespread evidence of bioaccumulation in soil fauna though the amount of bioaccumulation is not solely related to the soil concentration of PFAS[55]. Studies suggest that plant uptake of PFAS depends not only on the PFAS compound but also on the plant species with some species showing little difference in the uptake of long versus short chain PFAS whilst in other species uptake is of predominantly shorter chain PFAS (Blaine *et al* (2014)).[56] Current best practice guidelines for the application and use of biosolids in NZ[57] do not require the testing of biosolids for PFAS. Tremblay *et al*[58] identified PFAS as one of a number of emerging organic contaminants (EOCs) that should be considered during the revision of the NZ biosolids guidelines. In December 2017 the draft *Guidelines for the Beneficial Use of Organic Materials on Productive Land*[59] were released for public comment. These draft guidelines contain concentration limits for a number of EOCs, but do not set a concentration limit for PFAS. Several studies consider that PFOS and PFOA concentrations in biosolids are likely to have decreased and will continue to decrease since controls on PFOS and PFOA use were enacted following the inclusion of PFOS under the Stockholm Convention. However, evidence from a 2018 study[60] indicates that PFOS was one of the most common PFAS compounds detected in biosolids samples from 14 Australian wastewater treatment plants at a mean concentration of 25 ug/kg. It should also be noted that the presence of precursor products in biosolids, including those used as substitutes compounds could act as a long-term source of PFOS and PFOA[61].
Significance as source	There is clear evidence that biosolids derived from municipal wastewater treatment plants are likely to contain PFAS. The PFAS content of the biosolids will vary dependent on the source of the WWTP effluent from which the biosolids are derived. The potential for PFAS to leach from soils, accumulate in soils or be taken up by plants and animals varies considerably with climate, soils and animal/plant species. Biosolids derived from industrial process may or may not contain PFAS, depending on the particular activities of that industry. The highest PFAS concentrations in biosolids are likely to be those with industrial inputs and in extreme cases (where PFAS content in biosolids is extremely high) soils, surface water and groundwater may be contaminated above guideline values. There is uncertainty regarding the potential significance of biosolids from municipal plants (without significant industrial inputs) as a significant environmental source of PFAS.
Further work	Further, detailed review of monitoring data that directly relates to the fate and transport of PFAS applied in biosolids.

3.11 Aircraft Maintenance Facilities

Activity	Aircraft Maintenance Facilities. Includes: Use of PFAS containing aviation hydraulic fluids.
PFAS use details	In the manufacturing process for aviation hydraulic fluids, a PFOS substance or precursor such as potassium perfluorooctane sulfonate was used as an additive to the hydraulic fluids with a content of about or less than 0.1% and was apparently considered such a minor ingredient that it was not listed on the MSDS by Boeing[62]. Aviation hydraulic fluids based on non-fluorinated phosphate esters are used as an alternative to those with PFOS, however metal corrosion is a potential issue with these fluids and so the working life of these alternatives is substantially shorter. Fluorinated chemicals other than PFOS and which may not be a precursor are also used, though concerns regarding the persistence of at least one such substance has resulted in 3M ceasing its production[18]. There is highly conflicting data on the amount and proportion of PFOS used for hydraulic fluids, though one source has estimated that the total global market for fluorinated compounds in aircraft hydraulic fluids is approximately 2 tonnes per year[63]. No usage data has been identified for New Zealand. Usage is likely to vary according to the maintenance of particular aircraft. Based on instructional videos for the replacement of hydraulic oil, new oil is likely to have been stored in drum-sized units (200L) rather than bulk storage tanks.
Period of use	Likely coincided with jet aircraft travel, so assumed to have been used from 1950s. Lawful use ceased in NZ in 2011, though it is possible that stocks may have continued to have been used after this.
Location of activities	Major airports (predominantly associated with jet aircraft), aircraft maintenance facilities and military air bases.
Potential contamination mechanisms	Spillage from container during filling/emptying. Inappropriate disposal of waste oil. Aircraft accidents/incidents. Contamination of soils, groundwater and stormwater runoff possible.
Investigation/monitoring data	There is a considerable amount of PFAS monitoring data from commercial and military airfields which include aircraft maintenance facilities. However, the investigation data has not generally distinguished between firefighting foam and hydraulic fluids as a potential source of detected PFAS contamination. Perfluoroethylcyclohexane sulfonate (PFECHS) which is reportedly mainly used as an erosion inhibitor in aircraft hydraulic fluids has been detected in fish collected from the North American Great Lakes[64] indicating that contamination associated with PFAS compounds in hydraulic fluids may be widespread despite the relatively low volumes of fluids used in the aviation industry and the relatively low concentrations of PFAS in those substances.
Significance as source	Aircraft Maintenance facilities are considered to have a low to moderate potential to act as a point source of environmental PFAS contamination for the following reasons: • Where PFOS-containing hydraulic fluids are used, the volumes used and stored are likely to be relatively small, with PFOS present at a low concentration; and

	- Generally speaking, for reasons of aviation security and safety aircraft maintenance activities are proceduralised and the handling of new and waste fluids would be expected to be closely controlled. Historic substance handling practices may have been less stringent and the potential for waste fluids to have been inappropriately disposed near maintenance facilities cannot be discounted.
Further work	Clarify volumes of use and handling practices. Obtain additional monitoring data for hydraulic fluid-related contamination.

3.12 Pesticide manufacturing or formulation

Activity	Pesticide manufacture or formulation. Includes: HAIL A12 Pesticide manufacture.
PFAS use details	N-Ethyl perfluorooctane sulfonamide (known as sulfluramid), a PFOS related substance, has been used as an active ingredient in ant baits to control leaf-cutting ants, as well as for control of red imported fire ants, and termites in the US. PFOS and other fluorinated substances have also been used as inert ingredients in pesticides. All pesticide products containing sulfluramid were to be phased out in the USA by 2016. Trade names of insect baits used internationally and which may contain PFOS (including NZ) include "Finitron®" which is sulfluramid-based; however this and other sulfluramid-containing products were removed from the US market due to environmental concerns c.2002. Concentrations of sulfluramid in the insecticide are between 0.5% and 1% by weight. Other trade names include Raid Max® (SC Johnson) and Volcano® (Griffith Corporation). Sulfluramid production appears to have increased in Brazil since production ceased in the US[65]. ® wasp bait was given a 'limited sales experiment', with bait stations deployed in the Ashley Forest and Mt Thomas Forest areas in Canterbury[66]. Field trials comparing alternative wasp control insecticides were also conducted near Lake Rotoiti[67]. Although information is contradictory it would appear that Finitron® was being used in New Zealand as late as 2004[68]. This study has not identified any evidence to suggest that sulfluramid (or other PFAS-containing insecticides) were manufactured in New Zealand.
Period of use	Finitron® was manufactured in the US between 1994 and 2002 and appears to have been in limited use in New Zealand at this time. There is some evidence that use continued in controlled circumstances to as late as 2004.
Location of activities	No evidence of manufacture in NZ. Localised use in forestry areas in the central and north of the South Island.
Potential contamination mechanisms	Accumulation in forestry food chain. Localised ground contamination near bait stations. Release from dead wasp colonies.
Investigation/monitoring data	Monitoring of Brazilian surface water[65] where sulfluramid is used for controlling leaf cutter ants indicates PFOS concentrations of 0.001 ug/L which would exceed the ANZECC draft freshwater guidelines for 99% of species. However, given the scale of use in Brazil, it is unlikely that this concentration is indicative of the potential concentration in NZ surface waters given what appears to be a limited extent and duration of use in NZ.
Significance as source	The manufacture and use of PFAS-containing insecticides are considered to have a low to moderate potential to act as a source of contamination in New Zealand because: • There is no evidence indicating that the manufacture of these substances occurred in New Zealand; • Concentrations of PFOS in the insecticides was generally low (<1% by weight); • The volumes used are likely to be relatively small;

	• The period of use is relatively limited; and • The geographical extent of use was relatively limited.
Further work	Clarification of extent of use. Confirm that sulfluramid products were not manufactured in New Zealand.

4 Discussion and summary

4.1 Classification of potential PFAS sources

Industries and activities that have used large volumes of PFAS-containing substances over an extended period of time are, as with any contaminant, more likely to be associated with significant PFAS contamination than those where usage volumes are low or usage occurred over a relatively short time frame. However, any apparent differences between industries is complicated by the influence that operating practices at an individual site may have, and how practices have changed over time. Also, the significance of a particular source of contamination is to a large part related to the effect that that source is having or may have on human health or the wider environment, which is beyond the scope of this study. It is therefore possible that at a site level, any of the industries or sectors listed by the MfE could result in significant PFAS contamination. For those involved with the investigation of sites where industries or activities on the MfE list are or have been undertaken, as a starting point, PFAS should be included as a potential contaminant of concern and only eliminated when there is sufficient evidence to do so.

To assist with prioritisation, the list of industries/activities provided by the MfE has been divided into the following subsets:

- Waste disposal and treatment activities;
- High volume uses;
- Small scale/low volume uses; and
- Limited use activities.

4.1.1 Waste disposal and treatment activities

There is clear evidence that a waste disposal and treatment activities in developed countries are responsible for the environmental discharge of PFAS as an inadvertent consequence of otherwise ‘authorised’ discharges. Whilst there is an absence of New-Zealand-specific data to confirm this, based on New Zealand’s status as a developed country it is considered highly likely that these industries are sources of PFAS discharge in New Zealand. These industries/activities are:

- Waste disposal (landfills);
- Wastewater treatment plants; and
- Biosolids application.

There are international examples of where, in extreme cases (and usually associated with industrial wastes), discharges from these activities have resulted in the contamination of drinking water above guideline levels or standards. Some studies argue that the concentrations of PFOS, PFOA and PFHxS in discharges from these sources are likely to have decreased since controls on the use of PFOS and PFOA were put in place. However, there is also data to suggest that biosolids from WWTPs continue to contain elevated levels of PFOS and PFOA even in countries where POP controls have long since been put in place. Furthermore, by focussing on PFOS/PFOA we risk overlooking the continued high levels of precursor compounds and therefore potential long-term sources of PFOS and PFOA.

4.1.2 High volume users

A number of other industries/activities in the MfE list are associated with the use of relatively high volumes of PFAS-containing substances, albeit some may be in a highly diluted form. These industries may also be known for other contamination issues or handling practices which suggest a higher potential for PFAS contamination. These industries/activities are:

- Textiles, upholstery and leather;
- Metal plating and etching; and
- Paper products.

There is uncertainty regarding the actual extent and/or duration of use in these industries in New Zealand. However, all of the above are known to have occurred in New Zealand during the years of PFAS use. PFAS contamination has to date been identified in at least one metal plating facility in New Zealand, with contaminant concerns at that site warranting funding from the Contaminated Sites Remediation Fund. Those involved in the investigation of these sites that operated post 1940s should assume that it is highly likely that PFAS substances have been used unless a thorough historical review confirms otherwise.

4.1.3 Small scale/low volume uses

There is international evidence that this subset of industries/activities is associated with significant PFAS contamination issues. However, by international terms, the scale of these activities in New Zealand is likely to be small. Therefore, based on the information reviewed during this study, there is insufficient evidence to suggest that in New Zealand they should be considered as potentially significant as those industries and activities discussed above. These industries/activities are:

- Industrial surfactants, resins, moulds, plastics; and
- Photolithography, semiconductor industry.

4.1.4 Limited use activities

The final subset of industries comprises those for which available data indicates that the use of PFAS-containing substances was likely to have been of limited duration, limited in geographical extent or likely to have been used in a form such that there is a lower risk of significant soil, groundwater or surface water contamination occurring. These industries/activities are:

- Wire manufacture;
- Aircraft maintenance facilities; and
- Pesticide manufacture.

It is important to note that whilst the risk of significant PFAS contamination being associated with these activities is considered to be low, PFAS should not be dismissed as a potential contaminant of concern without site-specific information.

4.2 Other potential sources of PFAS contamination

During the completion of this study, it has become evident that there is a vast range of potential sources of PFAS due to the almost incalculable applications of these substances. Many of these sources and applications do not sit conveniently within a particular industry or activity. Nonetheless studies show that some may be as significant (and in some cases more significant) as sources – particularly for direct human exposure. These sources include (but are not limited to):

- Consumer electronics;
- Consumer/domestic cleaning products and surface treatments;
- Building products – including low/zero VOC paint, cement additives, fillers and adhesives; and
- Treated clothing.

These sources contribute to our daily PFAS exposure and may in some circumstances be at least as significant as the industrial sources discussed above.

5 Conclusions and recommendations

This study has confirmed that PFAS are or have likely been used in a wide range of activities within New Zealand and for an extended period. There is uncertainty regarding the relative significance of each industry or activity sector identified by the MfE in its 'Advice to Councils'. This is primarily due to the absence of readily available and New Zealand-specific usage and environmental monitoring data. In some cases, the availability of relevant data may be limited due to commercial sensitivity, but in many cases it is simply likely to reflect the fact that in New Zealand PFAS is an emerging contaminant issue.

Ranking industries or activities based on readily available international data risks overlooking the significant influence of New Zealand-specific and site-specific factors. In theory all industries and activities on the MfE list have the potential to be sources of PFAS contamination. That said, the available data does allow a crude distinction to be made between (i) those industries/activities from which the discharge of PFAS is almost certainly occurring, and PFAS should be considered contaminants of concern at all such locations in New Zealand; and (ii) those industries and activities where there is doubt over the use of PFAS at an industry or individual site level. Slightly different approaches will be required to further our understanding of the subsets defined in Section 4 as summarised below.

Industry/activity	**Potential further work**
Waste disposal and treatment activities: • Waste disposal (landfills); • Wastewater treatment plants; and • Biosolids application.	These facilities are generally council operated facilities in NZ with discharges authorised via resource consent, therefore: - Collate NZ specific monitoring data (if available) through councils; - Consider sampling at representative sites; and - Consider inclusion of PFAS analysis if evidence of leachate impact is noted (note that the NEMP requires monitoring for PFAS at landfill sites). Much of the readily available literature and research focusses on relatively extreme examples of where soil, groundwater or surface water have been impacted above acceptable levels by industrially derived wastes. Whilst further literature review is unlikely now to identify NZ-specific data, it may allow the compilation of monitoring data for international sites that are similar in the nature of waste input and treatment process to those in NZ.
High volume uses: • Textiles, upholstery and Leather; • Metal plating and etching; and • Paper products.	There is little known about the actual use of PFAS in these industries in New Zealand. Individual operators or industry groups may be reluctant to divulge usage information for commercial reasons and to avoid being named and shamed. Further understanding of these industries might be achieved through: - On the record joint agency approaches to operators and operator groups to establish usage; - The collation of site investigation data via Regional Councils and Territorial Authorities; and - Establish and maintain a database of PFAS monitoring data.

Small scale/low volume uses • Industrial surfactants, resins, moulds, plastics; and • Photolithography, semiconductor industry.	There is uncertainty regarding the scale of these operations in New Zealand: - Further detailed review of industries in New Zealand to establish scale and justification for further research. If justified by scale of industry: - On the record joint agency approaches to operators and operator groups to establish usage; - The collation of site investigation data via Regional Councils and Territorial Authorities; and - Establish and maintain database of PFAS environmental monitoring data.
Limited use activities: • Wire manufacture; • Aircraft maintenance facilities; and • Pesticide manufacture.	
Other sources:	• Identification of widespread non-industrial sources of PFAS exposure; and • Comparison of non-industrial versus industrial exposure.

6 Applicability

This report has been prepared by T+T for Environment Canterbury with respect to the particular brief given to us, by reference to applicable professional standards, guidelines, procedures and practices at the date of issue of this report. The purpose of this report is to provide generic guidance only. The application and interpretation of this report in specific circumstances is outside the control of Environment Canterbury and T+T, and is the sole responsibility of the user.

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