Rijkswaterstaat
Ministry of Infrastructure and Water Management

RWS INFORMATION

Sources of PFAS for Dutch surface waters

Research carried out on behalf of the Ministry of Infrastructure and Water Management, DGWB (Directorate General Water and Soil) for the Working Group on tackling substances of emerging concern

Date 14 July 2020

Status FINAL

Colophon

Published by	Water, Transport and Environment Safety and Water Water quality and Nature management
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Date	14 July 2020
Status	FINAL

Summary

PFAS is a group of anthropogenic chemicals, which are very poorly biodegradable, mobile in water, bio-accumulative and in some cases toxic. There are many concerns about these substances and much is still unknown about their spread to the environment. This research focuses on possible (diffuse) sources and routes of PFAS towards Dutch surface waters. Insight into the sources can be used to influence the spread of PFAS towards the environment.

This research was carried out by analysing single wastewater samples from selected companies from different sectors on the presence of PFAS. Indicative annual loads have also been calculated.

The measurements show that PFAS was found in the effluent in a number of sectors. These sectors are listed in the table below. For companies in the paper industry, sewage treatment plants and wastewater treatment plants, landfills for dredge spoil and soil and processors of construction, demolition and industrial waste, it is relevant to further investigate whether there is a structural release of PFAS, how this occurs and how it can be reduced.

Sector	Surface water source/route?	Remark
Waste sector		
Processors of construction, demolition and industrial waste	Yes	
Wastewater treatment		
Sewage treatment plants	Yes	Increased loads[a]
Wastewater treatment plants	Yes	Increased loads[a]
Reverse osmosis concentrate	Possible	
Extinguishing foam		
Aqueous film forming foam	Yes	
Soil processing, moving and dumping		
Landfills	Yes	Increased loads[a]
Industrial applications		
Synthetic fibre production	Possible	
Paper industry	Yes	Increased loads[a]
Cleaning and maintenance products		
Production of detergents and surfactants	Possible	The NVZ (Dutch association for detergents, maintenance products and disinfectants) states that no PFAS is added to detergents and cleaning products by their members.
Textiles		
Production of water-repellent textiles	Possible	
Other		
Tank cleaning	Possible	Depending on the amount of PFAS in the treated wastewater.

[a] Calculated loads are indicative due to the limited number of measurements.

The recommendations for the follow-up of this report are diverse, but are broadly as follows:

- For some sectors, it is recommended to investigate further the causes of PFAS emissions. This applies, for example, to the paper industry.
- In a number of cases, it is recommended to assess whether additional treatment is necessary. This applies, for example, to landfill sites for dredge spoil and soil.
- For a number of sectors it is not yet possible to say whether they are a relevant source or route of PFAS towards surface waters. Additional source research can then provide more clarity.

Contents

1 Introduction

1.1 Properties of PFAS

Perfluoroalkyl and polyfluoroalkyl substances, abbreviated to PFAS, are a group of anthropogenic, chemical substances with special properties. Their fluorinated carbon tail is both water and fat repellent. Due to the strong carbon-fluorine bonds, PFAS molecules are very stable, making them resistant to acids and heat, for example [1]. Since the 1940s, these favourable properties have been used, among other things, to make textiles water-repellent, to give pans a non-stick coating and to extinguish fires effectively.

There are many different PFAS compounds. More than 4700 PFAS compounds have been registered by the Organisation for Economic Cooperation and Development (OECD) [2] and this number may be growing. Roughly speaking, these substances can be divided into (I) polymers and (II) non-polymers. Polymers include fluoropolymers (e.g. polytetrafluoroethylene, also known as Teflon™), perfluoropolyethers and polymers with fluorinated side chains. These substances do not dissolve in water. They are too large to be absorbed into cells and therefore have no biological effects [3]. However, through wear and tear and degradation of the polymers, non-polymers can be released. This can also happen because non-polymers are used as processing aids to make (fluorine) polymers [4].
The non-polymers are often surfactants that are well soluble in water and can also be absorbed in cells [4].

1.2 Problematic substances

Worldwide, there are many concerns about PFAS, especially about the non-polymers. These molecules are very stable, which makes them very poorly degradable. PFAS are also bio-accumulative. In addition, the substances are very mobile and are found all over the world in water, soil and biota. For many of the PFAS compounds there are indications that they are toxic and a number of PFAS have been identified as a (potential) Substance of Very High Concern (SVHC).

PFAS is also receiving a lot of attention in the Netherlands. Due to the GenX process at the Chemours company and incidents involving the substances PFOS and PFOA, there is increasing social and policy attention for the substance group. In the meantime, a number of these substances containing fluorine have been found in virtually all surface waters, and at the end of 2019 PFAS caused problems with PFAS-containing soil and dredge spoil. For these reasons, the Netherlands is pushing for a restriction on all substances in the PFAS group at European level [5].

Although there are many concerns about PFAS in the environment, the sources of PFAS are still unclear. It goes without saying that these fluorinated substances can be released by producers of PFAS, but there is only limited insight into where and what they are used for and can therefore be released into the environment and surface water. Understanding these sources and routes of PFAS is essential in order to limit the spread of PFAS towards the environment.

2 Purpose and design of the research

This study was carried out by Rijkswaterstaat WVL (Water, Traffic and Environment) on behalf of the Ministry of Infrastructure and Water Management, Directorate-General Water and Soil (I&W/DGWB), within the framework of the Working Group on tackling substances of emerging concern. There was cooperation with the RWS/CIV (Central Information Technology) laboratory, the RWS regional units and the Vechtstromen Water Board. Companies have cooperated constructively in this research.

2.1 Research objective

The objective of this research was to gain insight into possible (diffuse) sources and routes of PFAS for surface water in the Netherlands. This has been investigated by analysing wastewater from selected companies on the presence of PFAS. This report does not address risks and norm violations of PFAS.

2.2 Research design

A literature review has been carried out to identify which sectors may be using PFAS. Wastewater samples have been collected from a number of companies in these relevant sectors. These companies were selected on the basis of expert judgement of RWS/WVL and enforcers on the one hand, and the possibility of sampling on the other hand. These companies include both direct and indirect dischargers. Wherever possible, aggregate samples have been collected over 24 hours, otherwise a random sample has been taken. An attempt has been made to select representative samples, but it should be noted that these are single samples on the basis of which a picture is formed of discharges with PFAS.

In addition to wastewater samples, some other samples have been included in this study because of their social relevance, including, for example, non-stick pans. In the original plan of approach it was also proposed to carry out a number of PFAS analyses of (consumer) products. Examples would include textile sprays and cleaning agents. It appeared that laboratories have major problems analysing such concentrated samples and therefore do not accept them. For this reason, no analysis of (consumer) products possibly containing PFAS has been carried out.

2.3 Analysis and analysed substances

The wastewater samples in this research were analysed with a target substance analysis for a number of PFAS compounds. These analyses were carried out by Wageningen Food and Safety Research (WFSR) according to the validated method SOP-A-1114. The list of analysed substances[1] and the associated limits of quantification (LOQ) are given in Appendix 1.

Some dry matter samples were also collected in this research. These have been analysed by Eurofins Omegam. For these analyses, too, the list of analysed substances and limits of quantification can be found in Appendix 1.

The disadvantage of target substance analysis is that it only provides insight into a very limited number of the thousands of known PFAS compounds. However, it is

[1] The PFAS compounds 6:2 FTS and EtFOSAA were not analysed. Because these substances are found in elevated concentrations in Dutch waters [55], it was asked whether WFSR could develop methods for these PFAS components. However, the methods could not be developed on time.

assumed that PFAS components never come alone, but always as a mixture of different compounds. The substances PFOS, PFOA and PFHxS can be seen as indicators of the presence of a wide variety of PFAS compounds [6]. In this way, a target substance analysis provides insight into the degree of pollution by PFAS. In order to get a picture of the fluorinated substances outside the target substance analysis, a number of samples was also analysed on adsorbable organic fluorine (AOF) by the German Water Centre (TZW). An AOF analysis is a total fluorine method, which analyses the amount of fluorine in organic compounds, including PFAS.

2.4 Relationship to other source studies

Because the substance group PFAS is of particular interest, various studies are being carried out into the sources of these substances in the Netherlands. Each of these investigations has a different purpose and a different approach.

By means of a joint advisory group of the Ministry of Infrastructure and the Water Management, it has been ensured that a number of these studies are closely aligned with each other. In addition to this research, the following studies on PFAS in the Netherlands are involved in the advisory group:

1. Commissioned by I&W/DGMI (Directorate General Environment and International), Arcadis is carrying out a study on PFAS in products and waste streams in the Netherlands [7].
2. KWR Water Research Institute is developing suspect and non-target screening methods to map PFAS at vulnerable locations in the Netherlands [8].
3. The Netherlands Food and Consumer Product Safety Authority (NVWA) conducts research into exposure to PFAS via food contact materials.
4. Commissioned by I&W/DGWB (Directorate General Water and Soil), the National Institute for Public Health and the Environment (RIVM) is investigating PFAS in soil.
5. I&W/DGWB is conducting research into PFAS in building materials.
6. Deltares and RIVM were commissioned by I&W to carry out a study into the leaching of PFAS from dredging soil under field conditions.
7. Commissioned by the Foundation for Applied Water Research STOWA, a study is being set up into PFAS in influent, effluent and sewage sludge from sewage treatment plants.

3 Results of literature review

Since the beginning of this century, various scientific bodies and institutes have carried out research into the use and presence of PFAS in household and industrial products and processes and its release into the (aqueous) environment. The use of PFAS compounds is widespread due to their unique properties.

3.1 Routes towards the environment

PFAS compounds can be released in a number of ways [9]:

1) from products and processes in which PFAS is applied;
2) from products and processes with fluoropolymers containing PFAS as processing aids or as impurities;
3) by wear and tear and the breaking down of polymers that are (partially) fluorinated.

The substances may be released into the environment via wastewater from production sites and downstream users, via direct use in the environment and via leaching out from products. PFAS compounds may also be released into the environment after use of PFAS-containing products, e.g. through sewage treatment plants and/or waste treatment [9].

3.2 Sectors

On the basis of existing knowledge, a number of categories have been identified in which PFAS may be released towards surface waters. This overview does not include the production of PFAS and fluoropolymers, but instead the sectors where the use and/or release of PFAS has not yet been properly mapped out. Reports on the release of PFAS at a Dutch production site of fluoropolymers in Dordrecht are publicly available [10]. Other PFAS production sites are located abroad [11].

3.2.1 Waste sector

Waste processors receive a very varied mixture of waste. This waste contains potentially PFAS-containing products, which may be released during waste processing. This means that the waste sector itself is not a source of PFAS in the sense that PFAS is used or made here, but the substances may be released to the environment.

3.2.2 Wastewater treatment

Sewage treatment plants and biological industrial wastewater treatment plants process sewage and industrial wastewater that may contain PFAS. Much is still unknown about the removal of PFAS in water treatment plants. According to data from the Watson database, PFAS is found in both influent and effluent from wastewater treatment plants [12]. PFAS from the wastewater streams can end up in surface water via these routes. As is the case with waste treatment plants, these water treatment plants are not a source, in the sense that they themselves use PFAS. PFAS in the effluent is probably caused by discharges into the sewer system.

3.2.3 Extinguishing foam

Extinguishing foam is a known significant source of PFAS in the environment [13] [14] [15] [16]. In the past, extinguishing foam often contained PFOS; nowadays this has been largely replaced by the substance 6:2 fluorotelomer sulfonate (6:2 FTS) [1]. Most of the extinguishing foam is used for extinguishing training. Fluorine-free foam should nowadays be used for these training purposes [17]. The Netherlands Fire

Service is investigating whether the foams for calamities can also be made fluorine-free [18].

3.2.4 *Soil processing, moving and dumping*

PFAS can also be released during the processing, repositioning and dumping of soil contaminated with PFAS. These substances may eventually end up in surface water via the collected percolating rainwater.

3.2.5 *Industrial applications*

There are several known industrial applications of PFAS. For example, for the concrete industry PFAS is mentioned as a possible constituent of formwork oil [19]. This oil can then end up in the wastewater via the rinse water. In addition, according to the Chemours website, PFAS can be used to make stone and concrete stain resistant and water and grease repellent [20].

In synthetic fibre production, PFAS may be used in the extrusion process, where the plastic is pressed through a mould [21]. Depending on the application, the synthetic fibres themselves can also be treated with PFAS.

In the metal industry, PFAS is used for safety reasons in the process of *metal plating* (chromium plating, anodising and staining). PFAS reduces the surface tension of the water, so that fog with, for example, chromium (VI) is not released into the air [9] [13] [14] [22].

In the paper industry, PFAS can be used in food contact materials (see also section 3.2.8), such as pizza boxes and disposable plates, or special paper products, such as glossy paper [22] [23] [24]. The substances containing fluorine can be released during the production of these paper articles, but also during waste paper processing.

PFAS polymers can also be used in electronics, for example for insulation, fire retardants and soldering [9] [25]. Finally, small quantities of PFAS are used in the photographic industry, photolithography and in semiconductor manufacturing [26].

3.2.6 *Cleaning and maintenance products*

PFAS compounds can be used in cleaning and maintenance products for both domestic and industrial use [27] [28] [29]. The Chemours website also states that PFAS is used in professional cleaning products, polishes and waxes [30]. For example, perfluorinated compounds can be used in polishes for cars and floors [29].

The NVZ, the Dutch association for detergents, maintenance products and disinfectants, states when questioned that no fluorinated alkyl compounds are added to detergents and cleaning products. They state that if PFAS components are found anyway, it is probably due to contamination of the raw materials used [31].

The NVZ indicates that no PFAS compounds with long carbon chains (C8 or longer) are added to maintenance products such as impregnation agents and floor waxes. Polymers with short fluorinated side chains are sometimes used in very low concentrations in these maintenance products. These substances may possibly degrade to PFHxS and PFHxA, but it is unknown to what extent this happens. Exact quantities are not known and suppliers of these products are reluctant to provide this information [31].

3.2.7 *Textiles*

Textiles may contain PFAS compounds that make the material water and dirt-repellent [27] [28] [29] [32]. Well-known examples are the sprays and detergents that can be used for shoes and clothing. There are also indications that PFAS compounds are used by dry cleaners [22]. Special waterproof clothing of most brands also contains PFAS polymers [28] [33] [34].

In carpets, PFAS can be used to make the material dirt-repellent both during production and cleaning [24] [25] [28] [35]. This means that the substances can also be released at carpet factories and processors.

Finally, PFAS is used in car interiors to make the upholstery dirt-repellent [35]. It is to be expected that these substances could be released, for example, at car dismantling sites.

3.2.8 *Food-related products*

Many non-stick pans contain a layer of fluoropolymers made with PFAS as processing aids, which may be released during use [36] [37] [38]. A risk to the water can arise when washing these pans. Silicone baking moulds have also been mentioned as a possible source of PFAS, but so far the quantities are too small to measure [27]. Greaseproof paper for food packaging and baking paper is made by treating the paper with PFAS polymers [27] [28] [36] [39] [40] [41] [42] [43]. The production of this greaseproof paper does not take place in the Netherlands, but the paper can be used here to wrap, for example, fast food. The PFAS compounds used could be released during waste paper processing and/or waste disposal.

3.3 Sectors and applications researched

Table 1 gives an overview of the number of samples collected per sector in this study.

Table 1. Overview of the number of samples collected per sector.
[a]: R stands for random sample, C24H stands for a sample that was collected over 24 hours.
[b]: D stands for direct discharge, I stands for indirect discharge
[c]: not included in this investigation due to logistical constraints.
[d]: not estimated to be relevant for surface water.

Sector	Number of samples	Type of sample[a,b]	Remark
Waste sector			
Waste processors	4	Wastewater, R, D	2 waste processors of construction, demolition and industrial waste and bulky household waste; 2 streams from a waste incineration plant for municipal and residual waste.
Incinerator bottom ash	4	Bottom ash	Not wastewater, but dry matter samples from the ashes of waste incineration plants.
Wastewater treatment			
Sewage treatment plants	4	Wastewater, R/C24H	
Wastewater treatment plants	3	Wastewater, R/C24H, D+I	
Reverse osmosis concentrate (R/O)	1	Wastewater, R, D	
Wastewater treatment by waste processors	0	-	The transport and treatment of PFAS-containing wastewater was investigated by the ILT in 2018 [44].

Sector	Number of samples	Type of sample[a,b]	Remark
Extinguishing foam			
Foaming agent	1	Undiluted product	
Training sites	0[c]	-	
Soil processing, moving and dumping			
Landfills	2	Wastewater, C24H, D	Effluent from the wastewater treatment plant
Soil remediation	1	Wastewater, R, D	
Major earthmoving	1	Wastewater, R, D	
Industrial applications			
Concrete industry	6	Wastewater, R, D	
Synthetic fibre production	2	Wastewater, R/C24H, I	
Metal industry	7	Wastewater, R/C24H, D	
Paper industry	4	Wastewater, R/C24H, D+I	
Photographic industry	0[d]	-	
Other	2	Wastewater, R, D+I	Cable manufacturer, tyre manufacturer
Cleaning and maintenance products			
Production of detergents and surfactants	1	Wastewater, R, I	
Production of cleaning products	1	Wastewater, C7D, I	
Car wash	1	Wastewater, R, I	
Run-off from motorways	3	Run-off water	
Textiles			
Water-repellent clothing	0	-	Greenpeace conducted a study on PFAS in water-repellent clothing [33].
Production of water-repellent textiles	1	Wastewater, C48H, I	
Dry cleaners	1	Wastewater, R, I	
Carpet industry	0[c]	-	
Tanneries	0[c]	-	
Car interiors	0[d]	-	
Food-related applications			
Non-stick pans	6	Extraction water	
Silicon baking moulds	0[d]	-	
Baking paper	0[d]	-	
Fast-food packaging materials	0[d]	-	

Sector	Number of samples	Type of sample[a,b]	Remark
Other			
Active carbon manufacturer	1	Wastewater, R,D	
Tank cleaning	1	Wastewater, C24H, I	
Rain water	2	Rain water	"blank" measurement

4 Results & discussion

Below is an overview of PFAS analysis results in wastewater per sector studied. The concentrations of the substances under investigation are given in ng/L in tables. In order to make the whole clear, a colour coding has been used, based on the concentration per substance:

colour coding:	0.1-10 ng/L	10-100 ng/L	100-1000 ng/L	>1000 ng/L

The limits of quantification (LOQs) of the substances analysed are given in Appendix 1. In the case of samples subject to LOQs other than those laid down in the Appendix, this is indicated in the results table. A laboratory with the lowest possible LOQ has been chosen for the analyses.

No water quality standards are available for most PFAS compounds. Only for PFOS, PFOA and HFPO-DA ("GenX") are set water quality standards; these are 0.65 ng/L, 48 ng/L and 118 ng/L respectively [45] [46] [47]. PFAS concentrations in surface water in the Netherlands vary between different locations and per PFAS component between 0 and a few nanograms per litre, with a single peak upwards [48].

For most of the sampled companies, indicative annual loads have also been calculated per measured PFAS compound. These calculations are set out in Appendix 2. These calculations assume that the PFAS concentrations in the sample are representative of the discharges over the whole year. This need not be the case. It should be stressed that these calculated loads are only indicative and may be overestimated. These values have therefore only been calculated for comparison purposes.

4.1 Waste sector

At four waste processors, the wastewater was analysed on the presence of PFAS (Table 2). Waste 1 and 2 are processors of construction, demolition and industrial waste and bulky household waste. Waste 3 and 4 are the wastewater streams from the acidic and alkaline after-treatment of a waste incineration plant for household and residual waste. In the end, these water streams are discharged directly.

Table 2. Analysis results of effluents from waste processors (ng/L). "<LOQ" indicates that the value is below the limit of quantification.

discharger	PFBA	PFPA	PFHxA	PFHpA	PFOA	PFNA	PFDA	PFUnA	PFDoA	PFTrDA	PFTeDA	PFBS	PFHxS	Br_PFHxS	PFHpS	PFOS	Br_PFOS	PFDS	HFPO-DA	DONA
waste 1	<LOQ	<LOQ	27.0	14.0	38.0	2.20	3.30	<LOQ	<LOQ	<LOQ	<LOQ	36.0	11.0	3.80	1.20	18.0	4.80	<LOQ	<LOQ	<LOQ
waste 2	<LOQ	120	57.0	11.0	17.0	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	42.0	1.70	<LOQ	<LOQ	19.0	3.60	<LOQ	<LOQ	<LOQ
waste 3	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	1.10	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
waste 4	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ

At both processors of construction, demolition and industrial waste, PFAS was found in the effluent in concentrations of several tens of nanograms per litre for different PFAS components, with a single outlier of 120 ng/L for PFPA at waste 2. In particular, PFAS compounds with shorter carbon chains were found (C4, C5, C6, C7 and C8). Because the flow rates of these two companies depend on the amount of rainwater, a load calculation is not possible here.

At the waste incineration plant (waste 3 and 4), no PFAS was found except for a small amount of PFBS (1.10 ng/L).

In addition to the effluent of a number of waste processors, four samples of incinerator bottom ash were analysed (Table 3). This is the residual product that remains after incineration and can then be used, for example, under motorways as raising or foundation material. Bottom ash 1 concerns incinerator slag that was used at the time in the construction of the N33 near Appingedam; this is an old sample. The remaining samples were collected in autumn 2019 from three active Dutch waste incineration plants.

Table 3. Analysis results of incinerator bottom ash (µg/kg). "<LOQ" indicates that the value is below the limit of quantification.

sample	PFBA	PFPA	PFHxA	PFHpA	PFOA	PFNA	PFDA	PFUnA	PFDoA	PFTrDA	PFTeDA	PFHxDA	PFODA	HPFHpA	8:2 FTUCA	H-PFUdA
bottom ash 1	<LOQ	<LOQ	0.100	<LOQ	1.10	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
bottom ash 2	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
bottom ash 3	<LOQ	<LOQ	<LOQ	<LOQ	0.200	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
bottom ash 4	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ

sample	L_PFBS	L_PFPeS	L_PFHxS	L_PFHpS	PFOS	L_PFDS	NC1yPFC4asfA	MeFBSAA	EtFOSA	EtFOSAA	4:2 FTS	6:2 FTS	8:2 FTS	10:2 FTS	HFPO-DA	ADONA	9Cl-PF3ONS	8:2 diPAP
bottom ash 1	<LOQ	<LOQ	<LOQ	<LOQ	1.80	<LOQ	<LOQ	<LOQ	<LOQ	1.20	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	0.100
bottom ash 2	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
bottom ash 3	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	0.600	0.300	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
bottom ash 4	0.700	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	4.90	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ

The measurement results show that the bottom ashes analysed contain little or no PFAS. No PFAS was found in incinerator bottom ash 2; in the other samples, a number of PFAS components have been found at levels between 0.100 and 4.90 µg/kg. The national background values as published in the adaptation of the PFAS Temporary Action Framework are 0.8 µg/kg for PFOA, 0.9 µg/kg for PFOS and 0.8 µg/kg for other PFAS compounds [49]. The measured levels are around these values with the exception of the level of 6:2 FTS (4.90 µg/kg) in bottom ash 4. The latter is remarkable, because 6:2 FTS is the active component in extinguishing foam.

A possible explanation for the low concentrations of PFAS in the effluent from the waste incineration plant and bottom ash samples is that incineration takes place in these plants. To completely decompose PFAS compounds into the gases hydrogen fluoride (HF) and carbon dioxide (CO_2), heating above 1,000 °C is required [1]. In the furnace of waste processors 3 and 4, the furnace temperature is 1,000 - 1,100 °C and PFAS compounds will therefore decompose [50]. At temperatures below 1,000 °C, PFAS can be partially degraded or converted to other fluorinated substances [51] [52]. Therefore, even at the mandatory minimum oven temperature of 850 °C, partial decomposition or conversion can already take place. It is unclear to what extent PFAS compounds in this process are completely broken down at a lower temperature or decompose into fluorinated substances that cannot be measured by target substance analysis. An analysis of total organic fluorine would provide more insight into this.

4.2 Wastewater treatment

For the wastewater treatment sector, effluents from four sewage treatment plants (STPs), three industrial wastewater treatment plants (WWTPs) and a reverse osmosis (R/O) plant were sampled (Table 4).

Table 4. Analysis results of effluents from sewage treatment plants, wastewater treatment plants and an R/O-installation (ng/L). "<LOQ" indicates that the value is below the limit of quantification.

discharger	PFBA	PFPA	PFHxA	PFHpA	PFOA	PFNA	PFDA	PFUnA	PFDoA	PFTrDA	PFTeDA	PFBS	PFHxS	Br_PFHxS	PFHpS	PFOS	Br_PFOS	PFDS	HFPO-DA	DONA
STP 1	<LOQ	32.0	49.0	9.30	18.0	1.10	1.60	<LOQ	<LOQ	<LOQ	<LOQ	46.0	14.0	1.00	<LOQ	20.0	8.80	<LOQ	3.10	<LOQ
STP 2	<LOQ	<LOQ	11.0	4.10	8.90	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	18.0	<LOQ	<LOQ	<LOQ	1.70	1.20	<LOQ	1.00	<LOQ
STP 3	<LOQ	130	300	14.0	21.0	1.20	1.40	<LOQ	<LOQ	<LOQ	<LOQ	21.0	2.00	<LOQ	<LOQ	5.10	2.90	<LOQ	<LOQ	<LOQ
STP 4	<LOQ	<LOQ	72.0	14.0	14.0	2.10	5.70	<LOQ	<LOQ	<LOQ	<LOQ	2.50	<LOQ	<LOQ	<LOQ	2.20	1.20	<LOQ	<LOQ	<LOQ
WWTP 1	<LOQ	<LOQ	42.0	25.0	25.0	46.0	9.70	<LOQ	<LOQ	<LOQ	<LOQ	4.70	1.50	<LOQ	<LOQ	55.0	21.0	<LOQ	<LOQ	<LOQ
WWTP 2	<LOQ	96.0	300	84.0	220	2.40	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	750	390	110	94.0	720	640	<LOQ	5.80	<LOQ
WWTP 3	<LOQ	<LOQ	3.50	1.20	23.0	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	7.30	3.10	<LOQ	<LOQ	1.40	1.10	<LOQ	<LOQ	<LOQ
R/O brine	100	150	140	59.0	50.0	6.6	2.7	<LOQ	<LOQ	<LOQ	<LOQ	47.0	13.0	3.90	1.10	16.0	7.70	<LOQ	38.0	<LOQ

The sampled sewage treatment plants were selected on the basis of the type of sewage being treated and the possibility of sampling. STP 1 treats industrial and domestic wastewater in the western part of the province Noord-Brabant, STP 2 treats wastewater in the province Overijssel, among others from the carpet processing industry, STP 3 treats wastewater in Overijssel and STP 4 treats wastewater in Overijssel, among others from the production of protective clothing.

PFAS was found in the effluent in all of the sewage treatment plants sampled. The concentrations of PFAS vary from a few to several tens of nanograms per litre. Outliers are the values for PFPA and PFHxA in STP 3 (130 and 300 ng/L, respectively).

Various PFAS components were found in all sampled sewage treatment plants. In particular, substances with short carbon chains were found, e.g. PFPA (C5), PFHxA (C6) and PFBS (C4). These substances were found in a few tens to hundreds of ng/L. PFAS compounds with a slightly longer chain such as PFHpA (C7) and PFOA and PFOS (C8) were found in lower concentrations of a few nanograms per litre. Long-chain PFAS components (from C9) were not present or only present in very low concentrations.

As the annual flow rates of sewage treatment plants are quite high, this also leads to high indicative annual loads (Table 25, Appendix 2). The calculations show that various PFAS compounds can be released on an annual basis in contents ranging from hundreds of grams to more than one kilogram. It should be stressed here that it is based on *indicative* annual loads which are based on a single sample which may not be representative.

Also for the biological industrial wastewater treatment plants, a selection for sampling has been made based on the type of wastewater and the possibility of sampling. WWTP 1 treats wastewater from around fifty companies, including offices, a fire brigade training centre, several chemical companies and a synthetic fibre producer. The influence of the fire service training centre is likely to be of limited influence on the results of this analysis, as extinguishing foam for exercises should not contain PFAS (see section 3.2.3). Should PFAS-containing foam nevertheless be used, it probably contains the PFAS component 6:2 FTS in particular (see section 4.3) and this substance is not included in analysed substances (see section 2.3). At WWTP 2, wastewater from various companies, including chemical producers and food companies, is treated centrally. WWTP 3 treats the wastewater from an industrial estate on which a number of companies in the plastics sector, among others, are located.

As with the sewage treatment plants, various PFAS components have been found in the effluent from the wastewater treatment plants, but there is a large spread in PFAS concentrations in the effluent between the different wastewater treatment plants. The effluents of WWTP 1 and 2 both contain PFAS concentrations of several tens to hundreds of nanograms per litre, while the effluent from WWTP 3 contains less than 10 ng/L except for one PFAS component. This difference is probably due to the difference in the type of plants discharging wastewater to the different treatment plants.

It is striking that WWTP 2 discharges the banned PFOS in high concentrations: 720 ng/L and 640 ng/L for PFOS and Br_PFOS, respectively. This is remarkable, because the use of PFOS has been banned for many years. PFAS compounds with chains longer than 10 carbon atoms were not found.

The combination of high PFAS concentrations in the effluent and high annual flow rates results in indicative annual PFAS loads of several tens to hundreds of grams of PFAS per year for the wastewater treatment plants (Table 25, Appendix 2). The highest loads were calculated for WWTP 2 and amount to more than one kilo per year for three of the PFAS compounds analysed (PFBS, PFOS and Br_PFOS).

The concentrated wastewater stream (the brine) of the reverse osmosis treatment plant contains high concentrations of PFAS: the substances PFBA, PFPA and PFHxA were found at concentrations above 100 ng/L. For these PFAS compounds, this leads to indicative annual loads of more than 100 g/year. The substances PFHpA, PFOA, PFBS and HFPO-DA were also present in concentrations of several tens of nanograms per litre.

In reverse osmosis, purified wastewater is upgraded to demineralised water by pressing it through a membrane. Salts and micropollutants are left behind in the concentrated stream, which is eventually released as wastewater. If PFAS is present in the supplied water, it is not surprising that the concentrated wastewater from the reverse osmosis contains increased concentrations of PFAS.

For sewage treatment plants and wastewater treatment plants, it should be stressed that although they are a source of PFAS towards the surface water, these dischargers are not the source itself. No PFAS is used in the treatment plants. PFAS in the effluent comes from wastewater or rainwater from other sources, which is treated at the treatment plant.

4.3 Extinguishing foam

For this study, one sample of undiluted aqueous film forming foam (AFFF 1) was analysed by the RWS laboratory on PFAS (Table 5). This AFFF is generally diluted with clean extinguishing water in a mixing ratio of 3% to extinguish fires.

Table 5. Analysis results of undiluted AFFF (ng/L). The values given are only an indication, because the extinguishing foam had to be greatly diluted in order to measure. The concentrations of the substances with "na" were too low to be measured.

sample	PFBA	PFPA	PFHxA	PFHpA	PFOA	PFNA	PFDA	PFUnA	PFDoA	PFTrDA	PFTeDA	8:2 FTUCA	L_PFBS	L_PFPeS	L_PFHxS	Br_PFHxS
AFFF 1	11,609	5,058	na	na	na	na	na	na	na	na	na	na	618	na	na	na

sample	L_PFHpS	L_PFOS	Br_PFOS	L_PFNS	L_PFDS	FOSA	N-MeFOSAA	N-EtFOSAA	4:2 FTS	6:2 FTS	8:2 FTS	HFPO-DA	DONA	9Cl-PF3ONS	11Cl_PF3OUdS
AFFF 1	na	na	na	na	na	na	na	na	na	77,858,874	na	na	na	na	na

It is clear that in this AFFF the substance 6:2 FTS has been used in particular (77,900,000 ng/L, 77.9 mg/L). It is known that this substance is widely used in extinguishing foams as a substitute for the banned PFOS. Taking into account a dilution factor of 33, the substance 6:2 FTS in released fire-fighting water may theoretically occur at a concentration of 2.4 mg/L. In addition to 6:2 FTS, lower concentrations of PFBA (11,609 ng/L), PFPA (5,058 ng/L) and L_PFBS (618 ng/L) are also present. These substances can therefore end up in the environment during fire-fighting activities.

4.4 Soil processing, moving and dumping

Four samples of effluents were collected and analysed for an investigation of the soil sector (Table 6). At both landfill sites investigated, contaminated soil and dredge spoil and (construction) waste are deposited at the sites investigated[2]. In addition, a wastewater sample was taken from a soil remediation project at a marshalling yard of the Dutch Railways and lastly the wastewater from a company in the major earthmoving sector was sampled and analysed.

Table 6. Analysis results of effluents from landfills and soil processors (ng/L). "<LOQ" indicates that the value is below the limit of quantification.

discharger	PFBA	PFPA	PFHxA	PFHpA	PFOA	PFNA	PFDA	PFUnA	PFDoA	PFTrDA	PFTeDA	PFBS	PFHxS	Br_PFHxS	PFHpS	PFOS	Br_PFOS	PFDS	HFPO-DA	DONA
landfill 1	1800	1600	2200	780	1400	49.0	12.0	<LOQ	<LOQ	<LOQ	<LOQ	16000	540	160	51.0	190	150	<LOQ	180	<LOQ
landfill 2	550	390	450	190	720	13.0	2.50	<LOQ	<LOQ	<LOQ	<LOQ	730	160	58.0	9.80	110	61.0	<LOQ	65.0	<LOQ
soil remediation 1	<LOQ	<LOQ	3.10	<LOQ	1.60	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	8.60	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
earthmoving 1	<LOQ	<LOQ	2.50	<LOQ	1.40	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	4.30	<LOQ	<LOQ	<LOQ	1.80	<LOQ	<LOQ	<LOQ	<LOQ

It is striking that the effluents from both landfills contain high concentrations of PFAS. Multiple PFAS compounds are present in both effluents in hundreds of nanograms per litre, up to 16,000 ng/L PFBS at landfill 1.

A varied mixture of PFAS components is released at both sites, with both short carbon chains and longer carbon chains. PFAS with carbon chains longer than C10 were not found in the wastewater. In both cases both perfluoroalkyl carboxylic acids and perfluoroalkyl sulfonic acids are present.

The load calculations for the landfill sites are set out in Table 27 in Appendix 2. Due to the relatively high PFAS concentrations in the effluents, the indicative annual loads for various PFAS compounds are between 100 and 350 g/year, with an outlier of 1.2 kg PFBS on an annual basis for landfill 1.

Not much PFAS is released from the soil remediation. The highest value found in the effluent is 8.60 ng/L PFBS. The release of fluorinated substances during soil remediation depends on the amount of PFAS in the soil and can vary per location.

Also the effluent of the company in major earthmoving contained hardly any PFAS: in this case, the highest measured concentration is 4.30 ng/L PFBS.

4.5 Industrial applications

4.5.1 Concrete industry

In order to estimate the release of PFAS in the concrete industry, wastewater samples were collected and analysed at six companies because of the possible application of PFAS in formwork oil (Table 7). In all cases, very little or no PFAS was found. The highest measured concentration is relatively low at 3.40 ng/L PFOA and only three different PFAS compounds were found: PFOA, PFBS and PFOS. As a result, the calculated indicative annual loads are also very low: the highest calculated value is 90.6 mg PFOA per year.

[2] In the Netherlands, there are only a few landfills that are allowed to accept soil and dredge spoil containing PFAS. The increased PFAS concentrations are not naturally caused by recently deposited PFAS-containing soils. PFAS from dumped soil and dredged material has to seep through the entire landfill layer before it ends up in the drainage water and this takes time. PFAS in the drainage water can possibly be explained by previously deposited sludge from sewage treatment plants and soil remediation.

Table 7. Analysis results of effluents from companies in the concrete industry (ng/L). "<LOQ" indicates that the value is below the limit of quantification.

discharger	PFBA	PFPA	PFHxA	PFHpA	PFOA	PFNA	PFDA	PFUnA	PFDoA	PFTrDA	PFTeDA	PFBS	PFHxS	Br_PFHxS	PFHpS	PFOS	Br_PFOS	PFDS	HFPO-DA	DONA
concrete 1	<LOQ	<LOQ	<LOQ	<LOQ	1.10	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
concrete 2	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	1.10	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
concrete 3	<LOQ	<LOQ	<5,00	<LOQ	3.40	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	1.00	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
concrete 4	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
concrete 5	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
concrete 6	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	1.80	<LOQ	<LOQ	<LOQ	1.10	<LOQ	<LOQ	<LOQ	<LOQ

These results suggest that the concrete industry is not a major source of PFAS emissions into surface waters. However, on the basis of this information it is not possible to draw this conclusion with certainty as it is not known whether formwork oil containing PFAS was used at the sampled plants. Formwork oil itself cannot be analysed with the regular methods for water analysis.

4.5.2 *Synthetic fibre production*

The wastewater from two synthetic fibre producers was analysed on PFAS (Table 8). Synthetic fibres from these companies are used for, among other things, protective clothing and artificial grass. PFAS was found in the wastewater of both plants. At the first company ('synth. fibre 1') the concentrations are relatively low, with the highest value being 20 ng/L for PFOA. This company has indicated that PFAS was used in the past, but is no longer used today. PFAS in the effluent would be caused by contamination from the past. The calculated indicative annual loads are quite low: the highest value is 18.7 g PFOA per year (Table 31, Appendix 2).

Table 8. Analysis results of effluents from synthetic fibre producers (ng/L). "<LOQ" indicates that the value is below the limit of quantification.

discharger	PFBA	PFPA	PFHxA	PFHpA	PFOA	PFNA	PFDA	PFUnA	PFDoA	PFTrDA	PFTeDA	PFBS	PFHxS	Br_PFHxS	PFHpS	PFOS	Br_PFOS	PFDS	HFPO-DA	DONA
synth. fibre 1	<LOQ	<LOQ	3.70	1.30	20.0	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	1.70	4.00	<LOQ	<LOQ	1.60	1.20	<LOQ	<4,00	<LOQ
synth. fibre 2	<LOQ	<LOQ	64.0	12.0	13.0	1.40	5.40	<LOQ	<LOQ	<LOQ	<LOQ	2.20	1.10	1.00	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ

The PFAS concentrations at the second company ('synth. fibre 2') are slightly higher. The concentration of PFHxA (64 ng/L) is particularly striking; for the other PFAS components present, the concentrations are below 20 ng/L. Because the flow rate of this company is unknown, no indicative annual loads can be calculated.

4.5.3 *Metal industry*

Seven companies in the metal industry were investigated (Table 9). Virtually no PFAS was found in the effluents from these plants: concentrations are below 10 ng/L with one exception. At this company, 'metal 6', only the substance PFOS (linear and branched) was found in the effluent. This company makes basic materials for tin cans, in which chromium can be used. Use of PFOS is permitted in the metal industry for hard chromium plating subject to boundary conditions.

Due to the low PFAS concentrations, the calculated indicative annual loads for the metal industry are also low (Table 33, Appendix 2). The highest calculated value is 6.8 g PFBS per year.

Table 9. Analysis results of effluents from companies in the metal industry (ng/L). "<LOQ" indicates that the value is below the limit of quantification.

discharger	PFBA	PFPA	PFHxA	PFHpA	PFOA	PFNA	PFDA	PFUnA	PFDoA	PFTrDA	PFTeDA	PFBS	PFHxS	Br_PFHxS	PFHpS	PFOS	Br_PFOS	PFDS	HFPO-DA	DONA
metal 1	<LOQ	<LOQ	<LOQ	<LOQ	1.30	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	2.10	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
metal 2	<LOQ	<LOQ	2.10	<LOQ	1.00	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	3.40	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
metal 3	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	2.60	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
metal 4	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	7.10	2.90	<LOQ	<LOQ	<LOQ
metal 5	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
metal 6	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	37.0	17.0	<LOQ	<LOQ	<LOQ
metal 7	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ

4.5.4 *Paper industry*

The treated wastewater from four companies in the paper industry was sampled and analysed (Table 10). The companies investigated process waste paper and produce new paper and cardboard. It is striking that three out of four companies ('paper 1', 'paper 2' and 'paper 4') have reasonably high PFAS concentrations in the effluent, ranging from a few nanograms per litre to almost 400 ng/L for different PFAS components. Although the perfluoroalkyl carboxylic acids are present in higher concentrations than the perfluoroalkyl sulfonic acids, it is notable that the effluent from 'paper 2' contains 110 ng/L of the banned PFOS and 63.0 ng/L of branched PFOS.

Table 10. Analysis results of effluents from companies in the paper industry (ng/L). "<LOQ" indicates that the value is below the limit of quantification.

discharger	PFBA	PFPA	PFHxA	PFHpA	PFOA	PFNA	PFDA	PFUnA	PFDoA	PFTrDA	PFTeDA	PFBS	PFHxS	Br_PFHxS	PFHpS	PFOS	Br_PFOS	PFDS	HFPO-DA	DONA
paper 1	<LOQ	380	230	36.0	100	6.00	<5,00	<LOQ	<LOQ	<LOQ	<LOQ	58.0	4.90	<LOQ	<LOQ	8.60	9.00	<LOQ	<LOQ	<LOQ
paper 2	<LOQ	190	94.0	35.0	92.0	71.0	19.0	<2,00	<LOQ	<LOQ	<LOQ	18.0	2.40	<LOQ	1.30	110	63.0	<LOQ	4.70	<LOQ
paper 3	<LOQ	<LOQ	2.60	<LOQ	2.40	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	5.60	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
paper 4	<LOQ	<LOQ	97.0	53.0	130	11.0	1.80	<LOQ	<LOQ	<LOQ	<LOQ	39.0	3.90	<LOQ	<LOQ	19.0	23.0	<LOQ	<LOQ	<LOQ

Because the companies 'paper 1' and 'paper 2' have calculated annual flows of more than 3 million m^3/year, the calculated indicative annual loads for these companies are also high (Table 35, Appendix 2). For example, 'paper 1' amounts to 1.3 kg of PFPA per year and for the other substances, both companies have calculated loads of hundreds of grams per year.

Unlike the other companies, 'paper 3' hardly discharges PFAS. The difference could be due to the fact that this company does not use recycled paper. This suggests that PFAS is mainly released during waste paper processing.

4.5.5 *Other Industrial*

In addition to the above-mentioned industrial applications of PFAS, two other companies have been investigated. One is a cable manufacturer, which has been included because PFAS can be used to insulate wires and cables. The second company is a tyre manufacturer. Wastewater from both plants was sampled and analysed (Table 11).

Table 11. Analysis results of effluents from other industrial applications (ng/L). "<LOQ" indicates that the value is below the limit of quantification.

discharger	PFBA	PFPA	PFHxA	PFHpA	PFOA	PFNA	PFDA	PFUnA	PFDoA	PFTrDA	PFTeDA	PFBS	PFHxS	Br_PFHxS	PFHpS	PFOS	Br_PFOS	PFDS	HFPO-DA	DONA
cable manufacturer 1	<LOQ	<LOQ	<LOQ	<LOQ	1.30	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
tyre manufacturer 1	<LOQ	<LOQ	14.0	6.00	15.0	1.90	1.00	<LOQ	<LOQ	<LOQ	<LOQ	6.00	6.90	2.20	<LOQ	7.30	3.20	<LOQ	<LOQ	<LOQ

No PFAS was found in the effluent except for 1.30 ng/L PFOA at the cable manufacturer. On the basis of this random sample, this does not appear to be a relevant source of PFAS. The PFAS concentrations found at the tyre manufacturer are slightly higher, but all below 20 ng/L. These are relatively low concentrations. The calculated indicative annual loads are all below 1 g/year (Table 37, Appendix 2).

4.6 Cleaning and maintenance products

To investigate the cleaning and maintenance products sector, a producer of detergents and surfactants and a producer of cleaning products were sampled (Table 12). The effluent from the producer of detergents and surfactants ('cleaning 1') contains relatively high concentrations of different PFAS components.[3] In particular, perfluoroalkyl carboxylic acids were found at concentrations between 22 and 250 ng/L. Concentrations of perfluoroalkyl sulfonic acids were relatively low and ranged between 2 and 12 ng/L. Because the flow rate of this company is unknown, no load calculations can be made.

Table 12. Analysis results of effluents from detergent and cleaning product manufacturers (ng/L). "<LOQ" indicates that the value is below the limit of quantification. "na" stands for not available because the sample could not be analysed.

discharger	PFBA	PFPA	PFHxA	PFHpA	PFOA	PFNA	PFDA	PFUnA	PFDoA	PFTrDA	PFTeDA	PFBS	PFHxS	Br_PFHxS	PFHpS	PFOS	Br_PFOS	PFDS	HFPO-DA	DONA
cleaning 1	190	250	160	210	79.0	74.0	22.0	<LOQ	<LOQ	<LOQ	<LOQ	7.10	5.80	2.30	<LOQ	12.0	5.30	<LOQ	<LOQ	<LOQ
cleaning 2	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na

The detergent producer's effluent ('cleaning 2') contained such a quantity of soap that analysis by the laboratory was not possible. Therefore, no analytical results are available for this sample.

The maintenance products were investigated by focussing on the polishes that can be used for cars. The wastewater from a car wash was analysed and in addition, three samples of motorway run-off were collected (Table 13). Due to the availability of the samples from another project (CEDR), the run-off samples taken in Sweden and Germany have been used.

Table 13. Analysis results of a carwash effluent and samples of run-off road water (ng/L). "<LOQ" indicates that the value is below the limit of quantification. The limits of quantification for 'run-off 3' are higher than usual due to a too small sample volume.

discharger / sample	PFBA	PFPA	PFHxA	PFHpA	PFOA	PFNA	PFDA	PFUnA	PFDoA	PFTrDA	PFTeDA	PFBS	PFHxS	Br_PFHxS	PFHpS	PFOS	Br_PFOS	PFDS	HFPO-DA	DONA
car wash 1	<LOQ	<LOQ	7.40	3.70	20.0	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	4.80	1.60	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
motorway run-off 1	<LOQ	<LOQ	<LOQ	1.80	2.20	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
motorway run-off 2	<LOQ	<LOQ	<LOQ	<LOQ	2.30	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
motorway run-off 3	<130	<130	<10,0	<5,00	<5,00	<5,00	<5,00	<5,00	<130	<130	<130	<5,00	<5,00	<5,00	<5,00	<5,00	<5,00	<5,00	<5,00	<5,00

It turns out that the effluent from the car wash contains very small amounts of PFAS. The highest measured concentration is for PFOA and is 20.0 ng/L. The annual flow rate of this company is unknown, so no load calculations have been made. These results suggest that the polish for cars is not a major risk for PFAS towards surface waters. It should be noted that this conclusion is based on a single random sample; However, the assumption is that car washes use similar products. The three samples of motorway run-off all contained little or no PFAS.

[3] Members of the NVZ (Dutch association for detergents, maintenance products and disinfectants) indicate that no PFAS is used in their products. PFAS was found at this company (not an NVZ member).

4.7 Textiles

For the textile sector, the effluents of two companies were analysed (Table 14). 'Textile 1' is a manufacturer of water-repellent textiles and at this company, PFAS was found in the effluent. In particular, the substance PFHxA seems to be used, and was present in the wastewater at 270 ng/L. The substances PFPA, PFHpA and PFOA were also found in a few tens of nanograms per litre. The concentrations of PFOS and Br_PFOS are very low. Load calculations have not been carried out because the annual flow rate of this company is unknown.

Table 14. Analysis results of effluents from companies in the textile industry (ng/L). "<LOQ" indicates that the value is below the limit of quantification.

discharger	PFBA	PFPA	PFHxA	PFHpA	PFOA	PFNA	PFDA	PFUnA	PFDoA	PFTrDA	PFTeDA	PFBS	PFHxS	Br_PFHxS	PFHpS	PFOS	Br_PFOS	PFDS	HFPO-DA	DONA
textile 1	<LOQ	64.0	270	22.0	32.0	6.00	7.10	<LOQ	<LOQ	<LOQ	<LOQ	1.00	<LOQ	<LOQ	<LOQ	2.90	1.20	<LOQ	<LOQ	<LOQ
dry cleaner 1	<LOQ	<LOQ	6.10	2.70	7.90	2.10	2.50	1.10	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	9.10	2.00	<LOQ	7.60	<LOQ

The effluent from 'dry cleaner 1' contains low concentrations of PFAS: the values are below 10 ng/L for all PFAS components found. A possibility is that the dry cleaner does not use PFAS-containing products, but that a small amount of PFAS is released when cleaning PFAS-containing textiles.

4.8 Food-related products

PFAS from non-stick pans possibly pose a risk to the water, because the substances can eventually end up in the surface water via washing up and sewage. To investigate this, extraction experiments were carried out with three different pans to determine the leaching of PFAS from the pans. This was done with a new pan that had never been used before (pan 1), a pan that had been in use for several months (pan 2) and an old pan with scratches (pan 3).

For extraction, the pans were filled with clean water (ULC/MS-CC/SFC, brand: Biosolve) at room temperature. This water was then heated to 100 °C at full capacity. The water was then boiled in the pan for 20 minutes without stirring. The pan was covered with a stainless steel lid (Figure 1). The water was then cooled in the pan, after which the sample bottles were filled with a stainless steel spoon. The extraction was carried out twice for each pan. The analysis results are shown in Table 15.

Figure 1. Standard setup for the extraction of non-stick pans with boiling water.

Table 15. Analysis results of extractions from non-stick pans (ng/L). "<LOQ" indicates that the value is below the limit of quantification.

sample	PFBA	PFPA	PFHxA	PFHpA	PFOA	PFNA	PFDA	PFUnA	PFDoA	PFTrDA	PFTeDA	PFBS	PFHxS	Br_PFHxS	PFHpS	PFOS	Br_PFOS	PFDS	HFPO-DA	DONA
pan 1, extr. 1	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
pan 1, extr. 2	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
pan 2, extr. 1	<LOQ	<LOQ	<LOQ	<LOQ	1.10	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	1.10	<LOQ	<LOQ	<LOQ	<LOQ
pan 2, extr. 2	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
pan 3, extr. 1	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
pan 3, extr. 2	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ

PFAS was found in only one of the samples, at the very low concentrations of 1.10 ng/L PFOA and 1.10 ng/L PFOS. From these simple extraction experiments it can be concluded that in these experiments, PFAS leaching by boiling water did not occur.

PFAS can possibly be released from non-stick pans in another way, for example by heating oil in a pan. These alternative routes have not been examined here.

4.9 Other

In the category "other", four samples were analysed (Table 16). Manufacturers of activated carbon (AC) do not use PFAS, but PFAS may be released during the reactivation of used activated carbon. The effluent from 'AC manufacturer 1' contains three different PFAS compounds, namely PFPA, PFHxA and PFBS. In particular, the values of the short PFAS components PFBA and PFBS (41.0 and 21.0 ng/L respectively) are slightly increased, but generally the effluent contains little PFAS. The calculated indicative annual loads show that these substances are all discharged with a load of less than 1 g/year (Table 45, Appendix 2).

Table 16. Analysis results of other samples (ng/L). "<LOQ" indicates that the value is below the limit of quantification.

discharger / sample	PFBA	PFPA	PFHxA	PFHpA	PFOA	PFNA	PFDA	PFUnA	PFDoA	PFTrDA	PFTeDA	PFBS	PFHxS	Br_PFHxS	PFHpS	PFOS	Br_PFOS	PFDS	HFPO-DA	DONA
AC manufacturer 1	<LOQ	41.0	3.80	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	21.0	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
tank cleaning 1 ww	950	<100	550	360	63.0	<4,00	4.20	<10,0	<LOQ	<LOQ	<LOQ	3.60	2.60	<LOQ	4.60	510	410	<LOQ	18.0	<LOQ
rain 1	<LOQ	<LOQ	4.20	1.60	6.60	<LOQ	1.10	<LOQ	<LOQ	<LOQ	<LOQ	1.60	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
rain 2	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ

High concentrations of PFAS were found in the wastewater sample collected at a tank cleaning company. In particular, the concentration of PFBA is high at 950 ng/L, but PFHxA, PFHpA and PFOS were also found in concentrations between 360 and 550 ng/L. Because the flow rate of this company is unknown, no indicative annual load is calculated.

In addition to a sample of the wastewater (ww), a sample of the sewage sludge (ss) of the tank cleaning company was freeze-dried and analysed on PFAS (Table 17). The high value of 900 µg/kg for 6:2 FTS is particularly striking in these results. Because 6:2 FTS was not included in the list of analysed substances for wastewater, it is not clear whether this substance was also present in the wastewater sample.

The ILT has carried out extensive research into PFAS pollution from the transport of PFAS-contaminated streams and subsequent tank cleaning [44] [53]. The amount of PFAS in the effluent depends on the load transported and therefore probably varies greatly. However, this sample does show that PFAS pollution in tank cleaners is a point of attention.

Table 17. Analysis results of sewage sludge from tank cleaning 1 (µg/kg). "<LOQ" indicates that the value is below the limit of quantification.

sample	PFBA	PFPA	PFHxA	PFHpA	PFOA	PFNA	PFDA	PFUnA	PFDoA	PFTrDA	PFTeDA	PFHxDA	PFODA	HPFHpA	8:2 FTUCA	H-PFUdA
tank cleaning 1 ss	0.700	0.300	2.40	2.30	1.20	0.100	0.400	0.800	0.400	0.300	0.200	0.100	0.100	1.80	0.600	<LOQ

sample	L_PFBS	L_PFPeS	L_PFHxS	L_PFHpS	PFOS	L_PFDS	NC1-PFC4asfA	MeFBSAA	EtFOSA	EtFOSAA	4:2 FTS	6:2 FTS	8:2 FTS	10:2 FTS	HFPO-DA	ADONA	9Cl-PF3ONS	8:2 diPAP
tank cleaning 1 ss	0.100	<LOQ	<LOQ	0.100	30.0	<LOQ	<LOQ	0.300	<LOQ	1.30	<LOQ	900	4.70	2.80	<LOQ	<LOQ	<LOQ	0.100

Finally, two rainwater samples collected in Lelystad and Krommenie were analysed (Table 16). The first sample ('rain 1') contains a few nanograms of a number of PFAS compounds; no PFAS was found in the second sample. At these locations, PFAS in rainwater is not relevant. However, rainwater may be a source of PFAS in the atmospheric plume of a point source [54].

4.10 AOF analyses

21 of the wastewater samples were also analysed for adsorbable organically fluorine (AOF) (Appendix 3). This method detects the presence of molecules containing fluorine, including PFAS. Only three of the analysed samples exceed the LOQ of 5 µg/L of adsorbable organofluorine compounds. This concerns the samples from WWTP 2 (5.0 µg/L), landfill 1 (9.4 µg/L) and the wastewater from tank cleaning 1 (21 µg/L) (Table 18). These values have been compared with total fluorine concentrations in the target substance analyses (Table 18, calculations in Appendix 3). For WWTP 2 and landfill 1, the fluorine concentrations found in the target substance analysis and the AOF measurement are of the same order of magnitude. This indicates that the target substance analysis gives a good picture of the total amount of PFAS in these samples. This is not the case for the wastewater sample from tank cleaning 1: the fluorine concentration in the target substance analysis is 1.99 µg/L, while the AOF concentration is 21 µg/L. This means that in addition to the measured PFAS compounds, other substances containing fluorine are also present in the sample. The measurement of sewage sludge at this discharger (Table 17) showed that the substance 6:2 FTS was present at a high concentration. The AOF analysis shows that 6:2 FTS may also be present in wastewater. This substance was not included the target substance analysis.

Table 18. Comparison of fluorine concentrations in target substance analysis and AOF analysis.

Discharger	Total fluorine concentration in target substance analysis (µg/L)[a]	AOF (µg/L)
WWTP 2	2.22	5.0
Landfill 1	15.1	9.4
Tank cleaning 1 ww	1.99	21

[a] calculated to total elemental fluorine in the different PFAS compounds

From the results of the AOF analyses it can mainly be concluded that the picture of high PFAS concentrations in a target substance analysis is confirmed by the AOF analysis. Conversely, in samples containing few of the analysed PFAS compounds, also less than 5 µg/L organically bound fluorine is found.

5 Conclusions

5.1 Sectors

In this study, random samples in the wastewater from various sectors were used to investigate whether PFAS may be present in the effluent. The results can be used to form a first insight into sources and routes of PFAS towards surface waters. On the basis of this research, further research into the sources and routes of PFAS can be carried out.

In Table 19 an overview is given of the sectors where sampling has taken place. This table also shows whether these measurements point to a possible source or route of PFAS towards surface waters. If this is clearly the case, this is indicated by an orange colour. A yellow colour indicates that a sector may be a source or route from PFAS to surface water.

Table 19. Overview of sampled companies per sector and their relevance for PFAS towards surface waters.

Sector	Number of samples	Surface water source/route?	Remark
Waste sector			
Processors of construction, demolition and industrial waste	2	Yes	
Waste incineration plants	2	Unclear	
Incinerator bottom ash	4	Unclear	
Wastewater treatment			
Sewage treatment plants	4	Yes	Increased loads[a]
Wastewater treatment plants	3	Yes	Increased loads[a]
Reverse osmosis concentrate (R/O)	1	Possible	
Extinguishing foam			
Aqueous film forming foam	1	Yes	
Soil processing, moving and dumping			
Landfills	2	Yes	Increased loads[a]
Soil remediation	1	Unclear	
Major earthmoving	1	Unclear	
Industrial applications			
Concrete industry	6	Does not seem relevant	
Synthetic fibre production	2	Possible	
Metal industry	7	Does not seem relevant	
Paper industry	4	Yes	Increased loads[a]
Cable manufacturer	1	Does not seem relevant	
Tyre manufacturer	1	Unclear	

Sector	Number of samples	Surface water source/route?	Remark
Cleaning and maintenance products			
Production of detergents and surfactants	1	Possible	The NVZ states that no PFAS is added to detergents and cleaning products by their members [31].
Production of cleaning products	1	Unclear	Sample could not be analysed.
Car wash	1	Does not seem relevant	
Motorway run-off	3	Does not seem relevant	
Textiles			
Production of water-repellent textiles	1	Possible	
Dry cleaners	1	Does not seem relevant	
Food-related applications			
Non-stick pans	6	Does not seem relevant	For a better picture of the release of PFAS from non-stick pans during frying, more research is needed; this is a point of attention for the NVWA.
Other			
Active carbon manufacturer	1	Unclear	
Tank cleaning	1	Possible	PFAS contamination depends on the amount of PFAS in the treated wastewater
Rain water	2	Does not seem relevant	

[a] Loads are indicative due to the limited number of measurements.

The table shows that PFAS was found in wastewater in the sectors shown in orange. These are processors of construction, demolition and industrial waste, wastewater treatment plants and sewage treatment plants, foam-forming agents in extinguishing foams, landfill sites and the paper industry. For all these sectors, the results are in line with the expectations based on the literature review. For the landfill sites, it is not possible to say on the basis of current research whether the measured PFAS comes from past or new landfill layers. The release of PFAS from the paper industry may have to do with special paper products and/or food contact materials. Further research into the latter category is being carried out by the NVWA.

In order to better quantify the contribution of these companies to PFAS in surface water, further research with more sampling is needed. In some cases this will require an analysis in sub-flows, for example in the wastewater treatment plants and the paper industry.

The sectors shown in yellow in the table may be a source or route for PFAS towards surface waters. However, this cannot yet be concluded with certainty on the basis of the samples in this investigation. More research is needed for this. This applies to reverse osmosis treatment, synthetic fibre production, the production of detergents and surfactants, the production of water-repellent textiles and tank cleaning.

There is a number of sectors in which no or hardly any PFAS was found in the samples examined here. These companies have not been coloured in Table 19. This is the case for a waste incineration plant, the concrete industry, the metal industry, a cable manufacturer, a tyre manufacturer, a car wash, motorway run-off, a dry cleaner, extraction water from non-stick pans and rainwater. As this is an exploratory study, it is not possible to draw a clear conclusion on the basis of these results whether these sectors are relevant to PFAS, but other sectors deserve more priority.

It should be stressed that many of the measurements are based on random samples which may not be representative. These conclusions are an indication on which follow-up research can be initiated.

5.2 Types of PFAS and AOF analysis

For all samples, mainly PFAS compounds with short to medium chain length were found (C4 - C8). PFAS components with a long carbon chain, such as PFDoA, PFTrDA and PFTeDA, were not found in any of the wastewater samples. There are two possible reasons for this. The first possibility is that these substances are used less than the short PFAS compounds. Another plausible option is that this result is caused by the fact that PFAS compounds with a long chain length are far less soluble in water than those with short chains. This also means that this research only paints a limited picture of exposure of poorly soluble PFAS compounds to the environment. However, these substances can spread into the environment via sewage sludge or food chains.

The analytical results show that both perfluoroalkyl carboxylic acids and perfluoroalkyl sulfonic acids are used. The choice of a type of PFAS will depend on the application. Extinguishing foam contains in particular the substance 6:2 FTS. The extent to which this substance is used in other sectors is not clear from this study.

In addition to targeted analysis on specific PFAS compounds, a determination of total organic fluorine (AOF analysis) was also carried out. Wastewater streams with higher concentrations of PFAS also showed an increased AOF value. In most wastewater samples, concentrations were below the rather high LOQ of 5 µg/L. The application of this method therefore does not have added value in all situations.

6 Recommendations

This research focuses on sources and routes of PFAS towards surface waters. On the basis of the conclusions, we make the following recommendations to limit these sources and routes:

1. The paper industry seems to be an important source of PFAS emissions into surface water. Here it is necessary to investigate what PFAS is used for and how discharge into surface water can be reduced. It is recommended to consult with the Dutch Association of Paper and Board Mills (VNP).
2. In the case of landfill sites, there is not much more to do on the source side. However, it is important to explore possibilities to reduce the PFAS concentrations in the effluent.
3. Effluents from sewage treatment plants appear to contain a lot of PFAS. Commissioned by STOWA, a study is currently being set up into PFAS in influent, effluent and sewage sludge from sewage treatment plants. There is no immediate need for additional action here.
4. In the studies currently being carried out by Arcadis on behalf of DGMI and the NVWA, it is recommended that attention be paid to the following products:
   - Detergents
   - Cleaning products
   - Textile sprays
   - Food contact materials and greaseproof paper

   This research into underlying causes is also important for emissions via wastewater treatment plants.
5. For a number of sectors it is not yet possible to estimate whether they are a source of PFAS towards surface water on the basis of this research. We therefore recommend that additional measurements are carried out at:
   - Firefighting training centres
   - Coating companies applying a Teflon coating
   - Artificial turf pitches, in connection with the possible application of PFAS in its production (synthetic fibre production).
6. Waste incinerators do not seem to contain much PFAS in the effluent based on the results. Because PFAS compounds can partially degrade to non-measurable substances during combustion, we recommend here to measure the total organic fluorine (e.g. with an AOF analysis) in the effluent of this type of company.
7. The Deltares report on preliminary PFAS contamination levels in sediment showed that the PFAS compounds 6:2 FTS and EtFOSAA are found in elevated concentrations in Dutch waters [55]. In this study, a laboratory capable of measuring low concentrations of PFAS was preferred to one capable of measuring many PFAS compounds. At the selected lab, the substances 6:2 FTS and EtFOSAA were not in the list of selected substances. It is advisable to include 6:2 FTS and EtFOSAA in a subsequent study in order to gain insight into the sources of these substances.

7 List of abbreviations

10:2 FTS	2-(perfluorodecyl)ethane-1-sulfonic acid
11Cl_PF3OUdS	11-chloroeicosafluoro-3-oxaundecane-1-sulfonic acid
4:2 FTS	2-(perfluorobutyl)ethane-1-sulfonic acid
6:2 FTS	2-(perfluorohexyl)ethane-1-sulfonic acid
8:2 diPAP	8:2 polyfluoroalkyl phosphate diester
8:2 FTS	2-(perfluorooctyl)ethane-1-sulfonic acid
8:2 FTUCA	8:2 fluorotelomer unsaturated carboxylic acid
9Cl-PF3ONS	9-chlorohexadecafluoro-3-oxanone-1-sulfonic acid
AC	activated carbon
ADONA	ammonium 4,8-dioxa-3H-perfluorononanoate
AFFF	aqueous film forming foam
AOF	Adsorbable Organic Fluorine
Br_PFHxS	perfluorohexane sulfonic acid (branched)
Br_PFOS	perfluorooctane sulfonic acid (branched)
C24H	Sample collected over 24 hours
C48H	Sample collected over 48 hours
C7D	Sample collection over a week
CIV	Centrale Informatievoorziening (Central Information Technology), national unit of Rijkswaterstaat
D	direct discharge
DGMI	Directoraat-generaal Milieu en Internationaal (Directorate General Environment and International)
DGWB	Directoraat-generaal Water en Bodem (Directorate General Water and Soil)
DONA	4,8-dioxa-3H-perfluorononanoic acid
EtFOSA	N-ethyl perfluorooctane sulfonamide
EtFOSAA	N-ethyl perfluorooctane sulfonamido acetic acid
HFPO-DA	2,3,3,3-tetrafluoro-2-(heptafluoropropoxy)propanoic acid ("GenX")
HPFHpA	7H-dodecafluoroheptanoic acid
H-PFUdA	2H,2H,3H,3H-perfluoroundecanoic acid
I	indirect discharge
I & W	Ministry of Infrastructure and Water Management
ILT	Inspectie Leefomgeving en Transport (Human Environment and Transport Inspectorate)
L_PFBS	perfluorobutane sulfonic acid (linear)
L_PFDS	perfluorodecane sulfonic acid (linear)
L_PFHpS	perfluoroheptane sulfonic acid (linear)
L_PFHxS	perfluorohexane sulfonic acid (linear)
L_PFOS	perfluorooctane sulfonic acid (linear)
L_PFPeS	perfluoropentane sulfonic acid (linear)
LOQ	Limit Of Quantification
MeFBSAA	N-methyl perfluorobutane sulfonamido acetic acid
na	not available; analytical result is not available
NC1yPFC4asfA	N-methyl perfluorobutane sulfonamide
ng/L	nanogram per litre
N-MeFOSAA	N-methyl perfluorooctane sulfonamide acetic acid
NVWA	Nederlandse Voedsel- en Warenautoriteit (Netherlands Food and Consumer Product Safety Authority)
NVZ	Nederlandse Vereniging van Zeepfabrikanten (Dutch association for detergents, maintenance products and disinfectants)

OECD	Organisation for Economic Co-operation and Development
PFAS	per- and polyfluoroalkyl substances
PFBA	perfluorobutanoic acid
PFBS	perfluorobutane sulfonic acid
PFCA	perfluoroalkyl carboxylic acid
PFDA	perfluorodecanoic acid
PFDoA	perfluorododecanoic acid
PFDS	perfluorodecane sulfonic acid
PFHpA	perfluoroheptanoic acid
PFHpS	perfluoroheptane sulfonic acid
PFHxA	perfluorohexanoic acid
PFHxDA	perfluorohexadecanoic acid
PFNA	perfluorononanoic acid
PFOA	perfluorooctanoic acid
PFODA	perfluorooctadecanoic acid
PFOS	perfluorooctane sulfonic acid
PFOSA	perfluorooctane sulfonamide
PFPA	perfluoropentanoic acid
PFSA	perfluoroalkyl sulfonic acid
PFTeDA	perfluorotetradecanoic acid
PFTrDA	perfluorotridecanoic acid
PFUnA	perfluoroundecanoic acid
R	random sample
R/O	Reverse osmosis
RIVM	Rijksinstituut voor Volksgezondheid en Milieu (National Institute for Public Health and the Environment)
RWS	Rijkswaterstaat
ss	sewage sludge
STOWA	Stichting Toegepast Onderzoek Waterbeheer (Foundation for Applied Water Research)
STP	sewage treatment plant
SVHC	Substance of Very High Concern
TZW	Technologiezentrum Wasser (German Water Centre)
VNP	Vereniging van Nederlandse Papier- en Kartonfabrieken (Dutch Association of Paper and Board Mills)
WFSR	Wageningen Food and Safety Research
WVL	Water, Verkeer en Leefomgeving (Water, Transport and Environment), national unit of Rijkswaterstaat
ww	wastewater
WWTP	wastewater treatment plant

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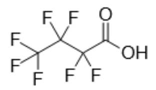
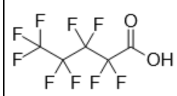
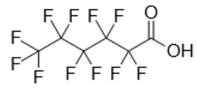
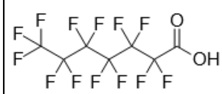
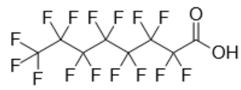
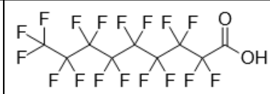
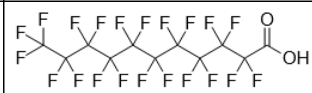
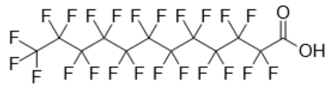
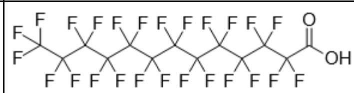
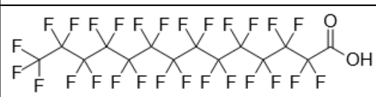
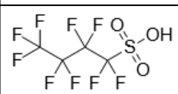
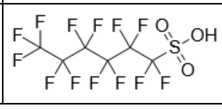
Appendix 1. Analysis and list of analysed substances

The wastewater samples have been analysed by Wageningen Food and Safety Research according to the validated method SOP-A-1114. The list of analysed substances is given in Table 20. The dry matter samples have been analysed by Eurofins Omegam on the substances in Table 21.

Table 20. List of analysed substances for wastewater.

PFAS component	Full name	Type	CAS number	LOQ (ng/L)	Chemical structure
PFBA	Perfluorobutanoic acid	C4, PFAA	375-22-4	25	
PFPA	Perfluoropentanoic acid	C5, PFAA	2706-90-3	25	
PFHxA	Perfluorohexanoic acid	C6, PFAA	307-24-4	2	
PFHpA	Perfluoroheptanoic acid	C7, PFAA	375-85-9	1	
PFOA	Perfluorooctanoic acid	C8, PFAA	335-67-1	1	
PFNA	Perfluorononanoic acid	C9, PFAA	375-95-1	1	
PFDA	Perfluorodecanoic acid	C10, PFAA	335-76-2	1	
PFUnA	Perfluoroundecanoic acid	C11, PFAA	2058-94-8	1	
PFDoA	Perfluorododecanoic acid	C12, PFAA	307-55-1	25	
PFTrDA	Perfluorotridecanoic acid	C13, PFAA	72629-94-8	25	
PFTeDA	Perfluorotetradecanoic acid	C14, PFAA	376-06-7	25	
PFBS	Perfluorobutane sulfonic acid	C4, PFSA	375-73-5	1	
L_PFHxS	Perfluorohexane sulfonic acid (linear)	C6, PFSA	355-46-4	1	

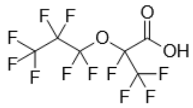
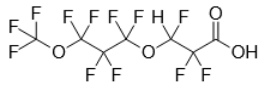
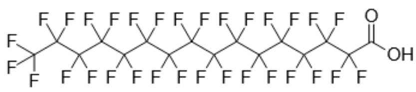
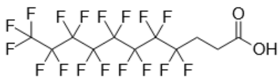
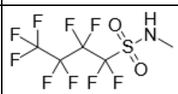
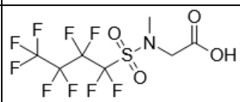
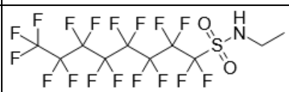
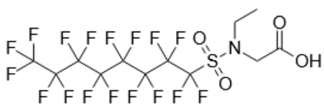
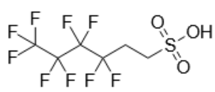
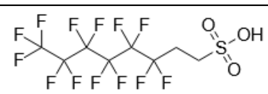
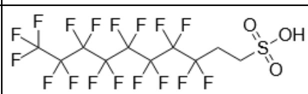
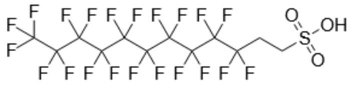
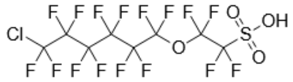
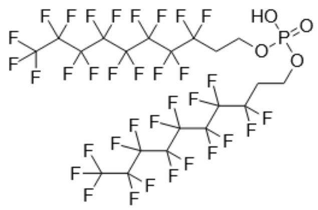
PFAS component	Full name	Type	CAS number	LOQ (ng/L)	Chemical structure
Br_PFHxS	Perfluorohexane sulfonic acid (branched)	C6, PFSA	-	1	
PFHpS	Perfluoroheptane sulfonic acid	C7, PFSA	375-92-8	1	
L_PFOS	Perfluorooctane sulfonic acid (linear)	C8, PFSA	1763-23-1	1	
Br_PFOS	Perfluorooctane sulfonic acid (branched)	C8, PFSA	-	1	
PFDS	Perfluorodecane sulfonic acid	C10, PFSA	335-77-3	1	
HFPO-DA	2,3,3,3-tetrafluoro-2-(heptafluoropropoxy)-propanoic acid ("GenX")		13252-13-6	1	
DONA	4,8-dioxa-3H-perfluorononanoic acid		919005-14-4	1	

Table 21. List of analysed substances for the dry matter samples.

PFAS component	Full name	Type	CAS number	LOQ (µg/kg)	Chemical structure
PFBA	Perfluorobutanoic acid	C4, PFCA	375-22-4	0,100	See Table 20
PFPA	Perfluoropentanoic acid	C5, PFCA	2706-90-3	0,100	See Table 20
PFHxA	Perfluorohexanoic acid	C6, PFCA	307-24-4	0,100	See Table 20
PFHpA	Perfluoroheptanoic acid	C7, PFCA	375-85-9	0,100	See Table 20
PFOA	Perfluorooctanoic acid	C8, PFCA	335-67-1	0,100	See Table 20
PFNA	Perfluorononanoic acid	C9, PFCA	375-95-1	0,100	See Table 20
PFDA	Perfluorodecanoic acid	C10, PFCA	335-76-2	0,100	See Table 20
PFUnA	Perfluoroundecanoic acid	C11, PFCA	2058-94-8	0,100	See Table 20
PFDoA	Perfluorododecanoic acid	C12, PFCA	307-55-1	0,100	See Table 20
PFTrDA	Perfluorotridecanoic acid	C13, PFCA	72629-94-8	0,100	See Table 20
PFTeDA	Perfluorotetradecanoic acid	C14, PFCA	376-06-7	0,100	See Table 20
PFHxDA	Perfluorohexadecanoic acid	C16, PFCA	67905-19-5	0,100	

PFAS component	**Full name**	**Type**	**CAS number**	**LOQ (µg/kg)**	**Chemical structure**
PFODA	Perfluorooctadecanoic acid	C18, PFCA	16517-11-6	0,100	
HPFHpA	7H-dodecafluoro-heptanoic acid	C7, PFCA	1546-95-8	0,400	
8:2 FTUCA	8:2 fluorotelomer unsaturated carboxylic acid	C8+2, PFCA	70887-84-2	0,400	
H-PFUdA	2H,2H,3H,3H-perfluoroundecanoic acid	C8+3, PFCA	34598-33-9	0,400	
L_PFBS	Perfluorobutane sulfonic acid (linear)	C4, PFSA	375-73-5	0,100	See Table 20
L_PFPeS	Perfluoropentane sulfonic acid (linear)	C5, PFSA	2706-91-4	0,100	
L_PFHxS	Perfluorohexane sulfonic acid (linear)	C6, PFSA	355-46-4	0,100	See Table 20
L_PFHpS	Perfluoroheptane sulfonic acid (linear)	C7, PFSA	375-92-8	0,100	See Table 20
PFOS	Perfluorooctane sulfonic acid	C8, PFSA	1763-23-1	0,100	See Table 20
L_PFDS	Perfluorodecane sulfonic acid	C10, PFSA	335-77-3	0,100	See Table 20
NC1yPFC4asfA	N-methyl perfluoro-butane sulfonamide	C4	68298-12-4	0,400	
MeFBSAA	N-methyl perfluorobutane sulfonamido acetic acid	C4	159381-10-9	0,100	
EtFOSA	N-ethyl perfluorooctane sulfonamide	C8	4151-50-2	0,100	
EtFOSAA	N-ethyl perfluorooctane sulfonamido acetic acid	C8	2991-50-6	0,100	
4:2 FTS	2-(perfluorobutyl)-ethane-1-sulfonic acid	C4+2	757124-72-4	0,100	
6:2 FTS	2-(perfluorohexyl)-ethane-1-sulfonic acid	C6+2	27619-97-2	0,100	
8:2 FTS	2-(perfluorooctyl)-ethane-1-sulfonic acid	C8+2	39108-34-4	0,100	

PFAS component	Full name	Type	CAS number	LOQ (µg/kg)	Chemical structure
10:2 FTS	2-(perfluorodecyl)-ethane-1-sulfonic acid	C10+2	120226-60-0	0,100	
HFPO-DA	2,3,3,3-tetrafluoro-2-(heptafluoropropoxy)-propanoic acid ("GenX")		13252-13-6	0,100	See Table 20
ADONA (DONA ammonium salt)	Ammonium 4,8-dioxa-3H-perfluorononanoate		958445-44-8	0,100	See Table 20
9Cl-PF3ONS	9-chlorohexadeca-fluoro-3-oxanone-1-sulfonic acid		756426-58-1	0,100	
8:2 diPAP	8:2 polyfluoroalkyl phosphate diester	2x C8+2	678-41-1	0,100	

Appendix 2. Load calculations

Explanatory notes to the calculations

The indicative annual loads of the sampled companies are calculated below. These calculations assume that the PFAS concentrations in the samples are representative of the discharges over the whole year. This need not be the case. That is why we can only talk about *indicative* annual loads.

In order to calculate these indicative annual loads on the basis of hourly flows, it has been assumed that companies operate on a continuous basis and discharge an average of 8,000 hours per year. For companies where a daily flow rate is available, 333 discharge days per year have been assumed; this corresponds to 8,000 discharge hours per year (8,000 / 24 = 333). Because daily flows can vary greatly throughout the year, the calculated loads may be higher than in reality. This can also be the case when a company only operates five out of seven working days.
For companies for which an annual flow rate of 2018 or 2019 was available, this was used.

No load calculations have been carried out for companies whose flow rate depends on the amount of rainwater. This also applies to companies whose flow rate is unknown.

The indicative annual loads have been calculated by multiplying the annual flow rate (if available) by the PFAS concentrations in the sample. The indicative loads are given in grams per year. In order to make the whole clear, a colour coding has been used, based on the indicative annual load:

colour coding:	0-1 g/year	1-10 g/year	10-100 g/year	>100 g/year

A grey colour indicates that the indicative annual load could not be calculated due to an unknown flow rate. This does not mean that the indicative annual load is 0.

Waste sector

Table 22. Calculation of annual flow rates for waste processors.

Discharger	Indicated flow rate	(Calculated) annual flow
Waste 1	rainwater-dependent	unknown
Waste 2	rainwater-dependent	unknown
Waste 3	on average 19 m^3/hour	152,000 m^3/year
Waste 4	on average 15 m^3/hour	120,000 m^3/year

Table 23. Indicative annual loads in the waste sector (g/year). "<LOQ" indicates that the PFAS concentration in the sample is below the limit of quantification. "na" means that the annual load could not be calculated due to an unknown flow rate.

discharger	PFBA	PFPA	PFHxA	PFHpA	PFOA	PFNA	PFDA	PFUnA	PFDoA	PFTrDA	PFTeDA	PFBS	PFHxS	Br_PFHxS	PFHpS	PFOS	Br_PFOS	PFDS	HFPO-DA	DONA
waste 1	<LOQ	<LOQ	na	na	na	na	na	<LOQ	<LOQ	<LOQ	<LOQ	na	na	na	na	na	na	<LOQ	<LOQ	<LOQ
waste 2	<LOQ	na	na	na	na	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	na	na	<LOQ	<LOQ	na	na	<LOQ	<LOQ	<LOQ
waste 3	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	0.167	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
waste 4	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ

Wastewater treatment

Data from recent years is available for the sewage treatment plants and an average annual flow rate for 2014-2018 has been used.

Table 24. Calculation of annual flow rates for waste processors.

Discharger	Indicated flow rate	(Calculated) annual flow
STP 1	37,741,314 m^3/year	37,741,314 m^3/year
STP 2	2,430,285 m^3/year	2,430,285 m^3/year
STP 3	14,156,733 m^3/year	14,156,733 m^3/year
STP 4	4,015,219 m^3/year	4,015,219 m^3/year
WWTP 1	1,866 m^3/day (on day of sampling)	621,378 m^3/year
WWTP 2	on average 200 m^3/hour [4]	1,600,000 m^3/year
WWTP 3	3,341,724 m^3/year (2018) [5]	3,341,724 m^3/year
R/O brine	on average 200 m^3/hour [5]	1,600,000 m^3/year

Table 25. Indicative annual loads in the waste sector (g/year). "<LOQ" indicates that the PFAS concentration in the sample is below the limit of quantification.

discharger	PFBA	PFPA	PFHxA	PFHpA	PFOA	PFNA	PFDA	PFUnA	PFDoA	PFTrDA	PFTeDA	PFBS	PFHxS	Br_PFHxS	PFHpS	PFOS	Br_PFOS	PFDS	HFPO-DA	DONA
STP 1	<LOQ	1208	1849	351	679	41.5	60.4	<LOQ	<LOQ	<LOQ	<LOQ	1736	528	37.7	<LOQ	755	332	<LOQ	117	<LOQ
STP 2	<LOQ	<LOQ	26.7	9.96	21.6	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	43.7	<LOQ	<LOQ	<LOQ	4.13	2.92	<LOQ	2.43	<LOQ
STP 3	<LOQ	1840	4247	198	297	17.0	19.8	<LOQ	<LOQ	<LOQ	<LOQ	297	28.3	<LOQ	<LOQ	72.2	41.1	<LOQ	<LOQ	<LOQ
STP 4	<LOQ	<LOQ	289	56.2	56.2	8.43	22.9	<LOQ	<LOQ	<LOQ	<LOQ	10.0	<LOQ	<LOQ	<LOQ	8.83	4.82	<LOQ	<LOQ	<LOQ
WWTP 1	<LOQ	<LOQ	26.1	15.5	15.5	28.6	6.03	<LOQ	<LOQ	<LOQ	<LOQ	2.92	0.932	<LOQ	<LOQ	34.2	13.0	<LOQ	<LOQ	<LOQ
WWTP 2	<LOQ	154	480	134	352	3.84	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	1200	624	176	150	1152	1024	<LOQ	9.28	<LOQ
WWTP 3	<LOQ	<LOQ	11.7	4.01	76.9	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	24.4	10.4	<LOQ	<LOQ	4.68	3.68	<LOQ	<LOQ	<LOQ
R/O brine	160	240	224	94.4	80.0	10.6	4.32	<LOQ	<LOQ	<LOQ	<LOQ	75.2	20.8	6.24	1.76	25.6	12.3	<LOQ	60.8	<LOQ

Extinguishing foam

Because for extinguishing foam only the pure foam-forming agent has been measured and not the diluted extinguishing foam used for extinguishing, no load calculations have been made for this.

Soil processing, moving and dumping

Table 26. Calculation of annual flow rates of landfill sites and soil processors.

Discharger	Indicated flow rate	(Calculated) annual flow
Landfill 1	on average 221 m^3/day	73,593 m^3/year
Landfill 2	459,000 m^3/year (2019)	459,000 m^3/year
Soil remediation 1	rainwater-dependent	unknown
Earthmoving 1	rainwater-dependent	unknown

Table 27. Indicative annual loads of landfills and soil processors (g/year). "<LOQ" indicates that the PFAS concentration in the sample is below the limit of quantification. "na" means that the annual load could not be calculated due to an unknown flow rate.

discharger	PFBA	PFPA	PFHxA	PFHpA	PFOA	PFNA	PFDA	PFUnA	PFDoA	PFTrDA	PFTeDA	PFBS	PFHxS	Br_PFHxS	PFHpS	PFOS	Br_PFOS	PFDS	HFPO-DA	DONA
landfill 1	132	118	162	57.4	103	3.61	0.883	<LOQ	<LOQ	<LOQ	<LOQ	1177	39.7	11.8	3.75	14.0	11.0	<LOQ	13.2	<LOQ
landfill 2	252	179	207	87.2	330	5.97	1.15	<LOQ	<LOQ	<LOQ	<LOQ	335	73.4	26.6	4.50	50.5	28.0	<LOQ	29.8	<LOQ
soil remediation	<LOQ	<LOQ	na	<LOQ	na	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	na	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
earthmoving 1	<LOQ	<LOQ	na	<LOQ	na	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	na	<LOQ	<LOQ	<LOQ	na	<LOQ	<LOQ	<LOQ	<LOQ

[4] Flow rate based on historical data from the RWS tool for Priority Substances (PST).
[5] This company discharges both directly and indirectly; the specified flow rate is the combination of these two flows.

Industrial applications

Concrete industry

Table 28. Calculation of annual flow rates of companies in the concrete industry.

Discharger	Indicated flow rate	(Calculated) annual flow
Concrete 1	5 m^3/day (on day of sampling)	1,665 m^3/year
Concrete 2	30 m^3/day (on day of sampling)	9,990 m^3/year
Concrete 3	80 m^3/day (on day of sampling)	26,640 m^3/year
Concrete 4	50 m^3/day (on day of sampling)	16,650 m^3/year
Concrete 5	rainwater-dependent	unknown
Concrete 6	50 m^3/day (on day of sampling)	16,650 m^3/year

Table 29. Indicative annual loads of companies in the concrete industry (g/year). "<LOQ" indicates that the PFAS concentration in the sample is below the limit of quantification.

discharger	PFBA	PFPA	PFHxA	PFHpA	PFOA	PFNA	PFDA	PFUnA	PFDoA	PFTrDA	PFTeDA	PFBS	PFHxS	Br_PFHxS	PFHpS	PFOS	Br_PFOS	PFDS	HFPO-DA	DONA
concrete 1	<LOQ	<LOQ	<LOQ	<LOQ	0.00128	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
concrete 2	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	0.0110	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
concrete 3	<LOQ	<LOQ	<LOQ	<LOQ	0.0906	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	0.0266	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
concrete 4	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
concrete 5	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
concrete 6	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	0.0300	<LOQ	<LOQ	<LOQ	0.0183	<LOQ	<LOQ	<LOQ	<LOQ

Synthetic fibre production

Table 30. Calculation of annual flow rates of synthetic fibre producers.

Discharger	Indicated flow rate	(Calculated) annual flow
Synth. fibre 1	932,800 m^3/year (2018)	932,800 m^3/year
Synth. fibre 2	unknown	unknown

Table 31. Indicative annual loads of synthetic fibre producers (g/year). "<LOQ" indicates that the PFAS concentration in the sample is below the limit of quantification. "na" means that the annual load could not be calculated due to an unknown flow rate.

discharger	PFBA	PFPA	PFHxA	PFHpA	PFOA	PFNA	PFDA	PFUnA	PFDoA	PFTrDA	PFTeDA	PFBS	PFHxS	Br_PFHxS	PFHpS	PFOS	Br_PFOS	PFDS	HFPO-DA	DONA
synth. fibre 1	<LOQ	<LOQ	3.45	1.21	18.7	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	1.59	3.73	<LOQ	<LOQ	1.49	1.12	<LOQ	<LOQ	<LOQ
synth. fibre 2	<LOQ	<LOQ	na	na	na	na	na	<LOQ	<LOQ	<LOQ	<LOQ	na	na	na	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ

Metal industry

Table 32. Calculation of annual flow rates of companies in the metal industry.

Discharger	Indicated flow rate	(Calculated) annual flow
Metal 1	48 m^3/day (on the day of sampling)	15,984 m^3/year
Metal 2	on average 250 m^3/hour	2,000,000 m^3/year
Metal 3	48 m^3/hour	384,000 m^3/year
Metal 4	174 m^3/day	57,942 m^3/year
Metal 5	190 m^3/day	63,270 m^3/year
Metal 6	185 m^3/day	61,605 m^3/year
Metal 7	248 m^3/day	82,584 m^3/year

Table 33. Indicative annual loads of companies in the metal industry (g/year). "<LOQ" indicates that the PFAS concentration in the sample is below the limit of quantification.

discharger	PFBA	PFPA	PFHxA	PFHpA	PFOA	PFNA	PFDA	PFUnA	PFDoA	PFTrDA	PFTeDA	PFBS	PFHxS	Br_PFHxS	PFHpS	PFOS	Br_PFOS	PFDS	HFPO-DA	DONA
metal 1	<LOQ	<LOQ	<LOQ	<LOQ	0.0208	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	0.0336	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
metal 2	<LOQ	<LOQ	4.20	<LOQ	2.00	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	6.80	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
metal 3	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	1.00	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
metal 4	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	0.411	0.168	<LOQ	<LOQ	<LOQ
metal 5	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
metal 6	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	2.28	1.05	<LOQ	<LOQ	<LOQ
metal 7	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ

Paper industry

Table 34. Calculation of annual flow rates of companies in the paper industry.

Discharger	Indicated flow rate	(Calculated) annual flow
Paper 1	9,976 m^3/day (on the day of sampling)	3,322,008 m^3/year
Paper 2	15,174 m^3/day (on the day of sampling)	5,052,942 m^3/year
Paper 3	9,005 m^3/day	2,998,665 m^3/year
Paper 4	309,797 m^3/year (2018)[6]	309,797 m^3/year

Table 35. Indicative annual loads of companies in the paper industry (g/year). "<LOQ" indicates that the PFAS concentration in the sample is below the limit of quantification.

discharger	PFBA	PFPA	PFHxA	PFHpA	PFOA	PFNA	PFDA	PFUnA	PFDoA	PFTrDA	PFTeDA	PFBS	PFHxS	Br_PFHxS	PFHpS	PFOS	Br_PFOS	PFDS	HFPO-DA	DONA
paper 1	<LOQ	1262	764	120	332	19.9	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	193	16.3	<LOQ	<LOQ	28.6	29.9	<LOQ	<LOQ	<LOQ
paper 2	<LOQ	960	475	177	465	359	96.0	<LOQ	<LOQ	<LOQ	<LOQ	91.0	12.1	<LOQ	6.57	556	318	<LOQ	23.7	<LOQ
paper 3	<LOQ	<LOQ	7.80	<LOQ	7.20	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	16.8	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
paper 4	<LOQ	<LOQ	30.1	16.4	40.3	3.41	0.558	<LOQ	<LOQ	<LOQ	<LOQ	12.1	1.21	<LOQ	<LOQ	5.89	7.13	<LOQ	<LOQ	<LOQ

Other Industrial

Table 36. Calculation of annual flow rates of other industrial companies.

Discharger	Indicated flow rate	(Calculated) annual flow
Cable manufacturer 1	12,945 m^3/year (2018)	12,945 m^3/year
Tyre manufacturer 1	50 m^3/day (on day of sampling)	16,650 m^3/year

Table 37. Indicative annual loads of other industrial applications (g/year). "<LOQ" indicates that the PFAS concentration in the sample is below the limit of quantification.

discharger	PFBA	PFPA	PFHxA	PFHpA	PFOA	PFNA	PFDA	PFUnA	PFDoA	PFTrDA	PFTeDA	PFBS	PFHxS	Br_PFHxS	PFHpS	PFOS	Br_PFOS	PFDS	HFPO-DA	DONA
cable manufacturer 1	<LOQ	<LOQ	<LOQ	<LOQ	0.0168	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
tyre manufacturer 1	<LOQ	<LOQ	0.233	0.100	0.250	0.0316	0.0167	<LOQ	<LOQ	<LOQ	<LOQ	0.100	0.115	0.0366	<LOQ	0.122	0.0533	<LOQ	<LOQ	<LOQ

Cleaning and maintenance products

Table 38. Calculation of annual flow rates of producers of detergents and cleaning products.

Discharger	Indicated flow rate	(Calculated) annual flow
Cleaning 1	unknown	unknown
Cleaning 2	unknown	unknown

[6] This company discharges both directly and indirectly; the specified flow rate is the combination of these two flows.

Table 39. Indicative annual loads of producers of detergents and cleaning products (g/year). "<LOQ" indicates that the PFAS concentration in the sample is below the limit of quantification. "na" means that the annual load could not be calculated due to an unknown flow rate.

discharger	PFBA	PFPA	PFHxA	PFHpA	PFOA	PFNA	PFDA	PFUnA	PFDoA	PFTrDA	PFTeDA	PFBS	PFHxS	Br_PFHxS	PFHpS	PFOS	Br_PFOS	PFDS	HFPO-DA	DONA
cleaning 1	na	na	na	na	na	na	na	<LOQ	<LOQ	<LOQ	<LOQ	na	na	na	<LOQ	na	na	<LOQ	<LOQ	<LOQ
cleaning 2	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na

Table 40. Calculate annual flow rates of a car wash and run-off road water.

Discharger	Indicated flow rate	(Calculated) annual flow
Car wash 1	unknown	unknown
Motorway run-off 1	n/a	unknown
Motorway run-off 2	n/a	unknown
Motorway run-off 3	n/a	unknown

Table 41. Indicative annual loads of a car wash and run-off road water (g/year). "<LOQ" indicates that the PFAS concentration in the sample is below the limit of quantification. "na" means that the annual load could not be calculated due to an unknown flow rate.

discharger	PFBA	PFPA	PFHxA	PFHpA	PFOA	PFNA	PFDA	PFUnA	PFDoA	PFTrDA	PFTeDA	PFBS	PFHxS	Br_PFHxS	PFHpS	PFOS	Br_PFOS	PFDS	HFPO-DA	DONA
car wash 1	<LOQ	<LOQ	na	na	na	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	na	na	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
motorway run-off	<LOQ	<LOQ	<LOQ	na	na	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
motorway run-off	<LOQ	<LOQ	<LOQ	<LOQ	na	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
motorway run-off	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ

Textiles

Table 42. Calculation of annual flow rates of companies in the textile industry.

Discharger	Indicated flow rate	(Calculated) annual flow
Textile 1	unknown	unknown
Dry cleaner 1	unknown	unknown

Table 43. Indicative annual loads of companies in the textile sector (g/year). "<LOQ" indicates that the PFAS concentration in the sample is below the limit of quantification. "na" means that the annual load could not be calculated due to an unknown flow rate.

discharger	PFBA	PFPA	PFHxA	PFHpA	PFOA	PFNA	PFDA	PFUnA	PFDoA	PFTrDA	PFTeDA	PFBS	PFHxS	Br_PFHxS	PFHpS	PFOS	Br_PFOS	PFDS	HFPO-DA	DONA
textile 1	<LOQ	na	na	na	na	na	na	<LOQ	<LOQ	<LOQ	<LOQ	na	<LOQ	<LOQ	<LOQ	na	na	<LOQ	<LOQ	<LOQ
dry cleaner 1	<LOQ	<LOQ	na	na	na	na	na	na	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	na	na	<LOQ	na	<LOQ

Food-related products

For the food-related products, only extraction experiments with non-stick pans have been carried out. That is why no load calculations have been carried out for this.

Other

Table 44. Calculation of annual flows of other discharges.

Discharger	Indicated flow rate	(Calculated) annual flow
AC manufacturer 1	on average 14 m^3/day	4,662 m^3/year
Tank cleaning 1	unknown	unknown
Rain 1	n/a	unknown
Rain 2	n/a	unknown

Table 45. Indicative annual loads of other samples (g/year). "<LOQ" indicates that the PFAS concentration in the sample is below the limit of quantification. "na" means that the annual load could not be calculated due to an unknown flow rate.

discharger / sample	PFBA	PFPA	PFHxA	PFHpA	PFOA	PFNA	PFDA	PFUnA	PFDoA	PFTrDA	PFTeDA	PFBS	PFHxS	Br_PFHxS	PFHpS	PFOS	Br_PFOS	PFDS	HFPO-DA	DONA
AC manufacturer 1	<LOQ	0.191	0.0177	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	0.0979	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
tank cleaning 1	na	<LOQ	na	na	na	<LOQ	na	<LOQ	<LOQ	<LOQ	<LOQ	na	na	<LOQ	na	na	na	<LOQ	na	<LOQ
rain 1	na	<LOQ	na	na	na	<LOQ	na	<LOQ	<LOQ	<LOQ	<LOQ	na	<LOQ	<LOQ	<LOQ	<LOQ	na	<LOQ	<LOQ	<LOQ
rain 2	na	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	na	<LOQ	<LOQ	<LOQ

Appendix 3. Results of AOF analyses

TZW analysed 21 of the wastewater samples on AOF. The LOQ for these analyses is 5 µg/L (5,000 ng/L). The results of the measurements are shown in Table 46.

Table 46. Results of AOF analyses (µg/L). "<LOQ" indicates that the value is below the limit of quantification of 5 µg/L.

discharger	AOF (µg/L)
STP 1	< LOQ
STP 2	< LOQ
STP 3	< LOQ
STP 4	< LOQ
WWTP 1	< LOQ
WWTP 2	5.0
WWTP 3	< LOQ
R/O brine	< LOQ
landfill 1	9.4
landfill 2	< LOQ
synth. fibre 1	< LOQ
synth. fibre 2	< LOQ
metal 6	< LOQ
paper 2	< LOQ
paper 3	< LOQ
paper 4	< LOQ
cleaning 1	< LOQ
cleaning 2	< LOQ
textile 1	< LOQ
AC manufacturer 1	< LOQ
tank cleaning 1 ww	21

A comparison between the results of the target substance analysis and the AOF measurement can be made by calculating the fluorine content per PFAS component in the target substance analysis using the formula

$$C_F = \frac{n \cdot M_F}{M_{PFAS}} \cdot C_{PFAS}$$

where C_F is the concentration of fluorine, *n* is the number of fluorine atoms in the PFAS molecule, M_F is the atomic mass of fluorine (19.00 u), M_{PFAS} is the molecular weight of the relevant PFAS component and C_{PFAS} is the concentration of the relevant PFAS component. For the PFAS components in the target substance analysis this data is shown in Table 47.

To illustrate: PFBA ($C_4HF_7O_2$) has 7 fluorine atoms and *n* x M_F equals 7 x 19.00 = 133.0. The molecular weight of PFBA is 214.0 g/mol. For a sample containing 25.0 ng/L PFBS, C_F is then equal to (133.0 / 214.0) x 25.0 = 15.5 ng/L. By performing this calculation for each measured PFAS component and adding up the results, the total fluorine concentration of the measured components is obtained. This value can be compared with the result of the AOF analysis.

For the three samples with a value above the LOQ in the AOF analysis, the fluorine concentration from the target substance analysis has been calculated (Table 48, Table 49 and Table 50).

Table 47. Molecular formulae, molecular masses and fluorine masses of the PFAS components in the target substance analysis.

PFAS component	Molecular formula	M_{PFAS} (g/mol)	n x M_F (g/mol)
PFBA	$C_4HF_7O_2$	214.0	133.0
PFPA	$C_5HF_9O_2$	264.0	171.0
PFHxA	$C_6HF_{11}O_2$	314.1	209.0
PFHpA	$C_7HF_{13}O_2$	364.1	247.0
PFOA	$C_8HF_{15}O_2$	414.1	285.0
PFNA	$C_9HF_{17}O_2$	464.1	323.0
PFDA	$C_{10}HF_{19}O_2$	514.1	361.0
PFUnA	$C_{11}HF_{21}O_2$	564.1	399.0
PFDoA	$C_{12}HF_{23}O_2$	614.1	437.0
PFTrDA	$C_{13}HF_{25}O_2$	664.1	475.0
PFTeDA	$C_{14}HF_{27}O_2$	714.1	513.0
PFBS	$C_4HF_9O_3S$	300.1	171.0
PFHxS	$C_6HF_{13}O_3S$	400.1	247.0
Br_PFHxS	$C_6HF_{13}O_3S$	400.1	247.0
PFHpS	$C_7HF_{15}O_3S$	450.1	285.0
PFOS	$C_8HF_{17}O_3S$	500.1	323.0
Br_PFOS	$C_8HF_{17}O_3S$	500.1	323.0
PFDS	$C_{10}HF_{21}O_3S$	600.1	399.0
GenX	$C_6HF_{11}O_3$	330.1	209.0
DONA	$C_7H_2F_{12}O_4$	378.1	228.0

Table 48. Calculation of fluorine concentrations for WWTP 2.

PFAS component	concentration (ng/L)	$C_F = (nM_F/M_{PFC})*C_{PFC}$ (ng/L)		
PFBA	25.0	15.5		
PFPA	96.0	62.2		
PFHxA	300	200		
PFHpA	84.0	57.0		
PFOA	220	151		
PFNA	2.40	1.67		
PFDA	1.00	0.702		
PFUnA	1.00	0.707		
PFDoA	25.0	17.8		
PFTrDA	25.0	17.9		
PFTeDA	25.0	18.0		
PFBS	750	427		
L_PFHxS	390	241		
Br_PFHxS	110	67.9		
PFHpS	94.0	59.5		
L_PFOS	720	465		
Br_PFOS	640	413		
PFDS	1.00	0.665		
HFPO-DA	5.80	3.67		
DONA	1.00	0.603		
Sum of C_F		2221	**2.22**	**µg/L**
AOF			**5.0**	**µg/L**

Table 49. Calculation of fluorine concentrations for landfill 1.

PFAS component	concentration (ng/L)	$C_F = (nM_F/M_{PFC})*C_{PFC}$ (ng/L)		
PFBA	1800	1118		
PFPA	1600	1036		
PFHxA	2200	1464		
PFHpA	780	529		
PFOA	1400	964		
PFNA	49.0	34.1		
PFDA	12.0	8.43		
PFUnA	1.00	0.707		
PFDoA	25.0	17.8		
PFTrDA	25.0	17.9		
PFTeDA	25.0	18.0		
PFBS	16,000	9116		
PFHxS	540	333		
Br_PFHxS	160	98.8		
PFHpS	51.0	32.3		
PFOS	190	123		
Br_PFOS	150	96.9		
PFDS	1.00	0.665		
HFPO-DA	180	114		
DONA	1.00	0.603		
Sum of C_F		15,123	**15,1**	**µg/L**
AOF			**9.4**	**µg/L**

Table 50. Calculation of fluorine concentrations for tank cleaning 1 ww.

PFAS component	concentration (ng/L)	$C_F = (nM_F/M_{PFC})*C_{PFC}$ (ng/L)		
PFBA	950	590		
PFPA	100	64.8		
PFHxA	550	366		
PFHpA	360	244		
PFOA	63.0	43.4		
PFNA	4.00	2.78		
PFDA	4.20	2.95		
PFUnA	10.0	7.07		
PFDoA	25.0	17.8		
PFTrDA	25.0	17.9		
PFTeDA	25.0	18.0		
PFBS	3.60	2.05		
PFHxS	2.60	1.60		
Br_PFHxS	1.00	0.617		
PFHpS	4.60	2.91		
PFOS	510	329		
Br_PFOS	410	265		
PFDS	1.00	0.665		
GenX	18.0	11.4		
DONA	1.00	0.603		
Sum of C_F		1989	**1.99**	**µg/L**
AOF			**21**	**µg/L**