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THE COST OF INACTION

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Preface

Purpose of this report

There is a growing demand for monetary values within chemical policy. The purpose of this report is to estimate the costs for society related to the negative effects and impacts on human health and environment due to the exposure to PFAS and C4-14 non-polymer fluoro-surfactants in particular. The purpose is also to highlight the economic case for taking effective and timely action to manage the risks of negative impacts.

The information in this report is intended to be used to raise awareness on the costs and long-term problems that the use of PFAS may cause for the environment and human health. The use of monetary values provides an additional important basis for strategical decisions within chemical agencies both at the national level as well as on the EEA level.

Disposition

The report is divided into three main parts. The first part provides a regulatory baseline and outlines the methodology to assess the socioeconomic costs related to the negative impacts on the environment and human health. The second part presents five case studies chosen for this study. They are aimed at illustrating the key pathways for impacts from PFAS and to gather information on actual costs incurred by society in reducing exposure to PFAS. The third part presents the estimates of health and environment-related costs of inaction linked to exposure to PFAS as well as the aggregated costs of inaction.

Scope and limitations

This study focuses on the C4-14 non-polymer fluoro-surfactants with the aim of providing a monetised estimate of total damage to health and the environment associated with PFAS exposures in the European Economic Area (EEA). The report therefore focuses on costs of inaction in the EEA countries. It uses data specific to Nordic countries when available, but also draws cost data from other European countries, the USA and Australia, where relevant. Not all costs can be quantified and monetised; some costs are therefore assessed qualitatively.

The study considers only the socioeconomic costs incurred by society due to impacts from PFAS exposures. It does not include or monetise costs for business such as for example substitution costs.

Financing and workforce

The study was carried out by Milieu Consulting in Brussels. Authors include Gretta Goldenman, Meena Fernandes, Tugce Tugran, Amanda Nordin, Cindy Schoumacher and Alicia McNeill from Milieu and Michael Holland from EMRC. The health economic models and calculations were developed and described by Meena Fernandes. The methodological framework for estimating costs for society, as well as the environmental economic models and calculations, were developed and described by Michael Holland.

The Nordic Chemical Group (NKG) has been the project principal. The steering group under NKG comprised members from Sweden, Denmark, Norway and Iceland, including Toke Winther and Lars Fock (The Danish Environmental Protection Agency), Audun Heggelund (Norwegian Environment Agency), Signe Krarup (The Danish Ministry of Environment and Food) and Åsa Thors (The Swedish Chemicals Agency). Experts supporting the steering group for parts of the project included Jenny Jans, Inger Cederberg, Mattias Carlsson Feng, Daniel Borg (The Swedish Chemicals Agency) and Ísak Sigurjón Bragason (The Environment Agency of Iceland).

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Background and case study information

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Summary

This study investigates the socioeconomic costs that may result from impacts on human health and the environment from the use of PFAS (per and polyfluoroalkyl substances). Better awareness of the costs and long-term problems associated with PFAS exposure will assist authorities, policy-makers and the general public to consider more effective and efficient risk management.

The production of PFAS, manufacture and use of PFAS-containing products, and end-of-life disposal of PFAS have resulted in widespread environmental contamination and human exposure. PFAS have been found in the environment all around the world and almost everyone living in a developed country has one or more PFAS in his/her body.

Because of the extreme persistence of PFAS in the environment, this contamination will remain on the planet for hundreds if not thousands of years. Human and environmental exposure will continue, and efforts to mitigate this exposure will lead to significant socioeconomic costs – costs largely shouldered by public authorities and ultimately taxpayers.

The focus of this study is on the costs of inaction with respect to regulation of PFAS in the countries comprising the European Economic Area (EEA). Costs of inaction are defined as the costs that society will have to pay in the future if action is not taken to limit emissions of PFAS today. The PFAS covered in this study are the C4-14 non-polymer fluorosurfactants.

The goal for the study has been two-fold:

1. to establish a framework for estimating costs for society related to negative impacts on health and the environment associated with PFAS exposure; and
2. to provide monetary values for those societal costs, documented by case studies.

Conclusions

The work of estimating the health and environment-related costs to society related to PFAS exposure has relied on the development of assumption-based scenarios. This reflects the limited data available in the academic literature, government documents and press reports. Whilst the uncertainties of the analysis need to be acknowledged, it is also important to recognise that, for several issues, there is little or no uncertainty:

1. PFAS are ubiquitous in the environment, and almost all people have PFAS in their bodies today. Monitoring in both Sweden and the USA concludes that around 3% of the population are currently exposed above proposed limit values, primarily through contamination of drinking water but also via other sources;
2. Many sources of PFAS exposure exist, linked to specialist applications (e.g. AFFFs for firefighting at airports and some industrial locations) and non-specialist uses (e.g. use in consumer goods such as pizza boxes, clothing and cosmetics);
3. Non-fluorinated alternatives for many of these uses are already on the market, and therefore certain uses of PFAS can be reduced;
4. The costs for remediating some cases of contamination run to many millions of EUR. Total costs at the European level are expected to be in the hundreds of millions of EUR as a minimum;
5. A large and growing number of health effects have been linked to PFAS exposure and evidence is mounting that effects occur even at background level exposures.

Current and proposed limit values for drinking water may be further reduced in recognition of growing information on, health and environmental risks. This would increase the costs of environmental remediation estimated here.

As explained throughout the study, the calculations rest on a number of assumptions, though these have been checked against e.g. data on costs incurred to ensure that they are linked to real-world experience. As more information becomes available, calculations will become more precise. Moreover, these findings are conservative. The figures are likely to get larger, in that the numbers of PFAS on the market and the volumes produced keep increasing. Further inaction will lead to more sources of contamination, more people exposed, and higher costs for remediation. The longer that PFAS contamination remains in the environment without remediation, the wider it will spread and the greater the quantity of soil or groundwater that will need to be decontaminated.

Methodology

Two methodologies have been developed, one for estimating health-related costs, the other for estimating costs of environmental remediation. Both methodologies are based on cases concerning exposure to PFAS. Data from the Nordic countries have been used when available, but the estimates also draw on cost data from other European countries, the USA and Australia, where relevant.

Impact pathways (the case studies)

Five case studies following the life-cycle of PFAS, from their production and use in product manufacturing, to the product's use and end-of-life disposal are used to illustrate how exposures to humans and the environment occur. Other instances of PFAS contamination provide additional data on direct costs incurred.

Case Study 1 considers exposures due to the production of PFAS in Europe. It reviews pollution linked to the Chemour factories in Dordrecht, Netherlands, the Miteni facility in the Veneto region of Italy, and the 3M plant near Antwerp, Belgium. The study estimates that up to 20 facilities actively produce fluorochemicals in Europe, that these facilities are significant sources of PFAS released to the environment, and that the exposure of workers at these plants is high.

The impacts from the manufacture and commercial use of PFAS-containing products are the focus of Case Study 2. Industrial activities with the potential to release PFAS to the environment include textile and leather manufacturing; metal plating, including chromium plating; paper and paper product manufacturing; paints and varnishes; cleaning products; plastics, resins and rubbers; and car wash establishments. The study assumes that a range of 3% to 10% of these facilities use PFAS. The study did not identify any fluorochemical production facilities in the Nordic countries. However, Eurostat statistics indicate that other industrial activities with the potential to release PFAS to the environment do take place in the region, such as metal plating and manufacture of paper products.

Case Studies 3 and 4 consider the use phase of PFAS-containing products. Case Study 3 examines exposure to PFAS-containing aqueous film-forming foams (AFFFs) used in firefighting drills and to extinguish petroleum-based fires. The AFFFs have contributed to groundwater contamination, especially around airports and military bases. Nearby communities have been affected by elevated levels of PFAS in their drinking water. Case Study 4 looks at PFAS-treated carpets, PFAS-treated food contact materials, and cosmetics as examples of how a product's use is likely to lead to direct human exposure through ingestion and dermal absorption. The use of products also result in releases to the environment when the product is washed off or laundered, entering sewers and treatment plants, and eventually waterways.

Case Study 5 looks at end-of-life impacts of PFAS-treated products. Municipal waste incineration may destroy PFAS in products if 1000 °C operating temperatures are reached. If landfilled, the PFAS will remain even after the product's core materials break down. The compounds will eventually migrate into liquids in the landfill, then into leachate collection systems or directly into the natural environment. They may then contaminate drinking water supplies, be taken up by edible plants and bioaccumulate in the food chain.

Health-related costs to society

To calculate health-related costs to society, the researchers looked for consensus regarding health endpoints affected by exposure to PFAS. Reviews of the scientific evidence have reached contradictory conclusions about the relevant health endpoints of human exposure to PFAS. However, some consensus has emerged concerning liver damage, increased serum cholesterol levels (related to hypertension), decreased immune response (higher risk of infection), increased risk of thyroid disease, decreased fertility, pregnancy-induced hypertension, pre-eclampsia, lower birth weight, and testicular and kidney cancer.

The methodology draws upon risk relationships developed in the course of specific epidemiological studies for populations exposed to PFAS at different levels. Workers exposed to PFAS in the workplace were used to exemplify a high level of exposure. Communities affected by PFAS, e.g. because of proximity to manufacturing sites or sites where fluorinated AFFFs were used, were assumed to have been exposed at a medium level; this level of exposure was assumed to have been experienced by 3% of the European population. The general population was considered to have experienced exposure at low (background) levels.

Table 1 provides an overview of the estimated annual costs for just a few health endpoints where risk ratios were available for affected populations. For example, the annual health-related costs for the elevated risk of kidney cancer due to occupational exposure to PFAS was estimated to be on the order of EUR 12.7 to EUR 41.4 million in the EEA countries. The estimated costs were substantially higher for elevated and background levels of exposure due to the greater number of persons affected. The total annual health-related costs, for the three different levels of exposure, was found to be at least EUR 2.8 to EUR 4.6 billion in the Nordic countries and EUR 52 to EUR 84 billion in the EEA countries.[1] Despite the high level of uncertainty and the assumptions underlying the calculations, the findings suggest that the health-related costs of exposure to PFAS are substantial.

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[1] The health-related costs due to occupational exposure to PFAS in the Nordic countries was not estimated due to an absence of information about the number and location of chemical production plants or manufacturing sites.

Table 1: Estimates of annual health impact-related costs (of exposure to PFAS)

Exposure level	"Exposed" population and source	Health endpoint	Nordic countries		All EEA countries	
			Population at risk	Annual costs	Population at risk	Annual costs
Occupational (high)	Workers at chemical production plants or manufacturing sites	Kidney cancer	n.a.	n.a.	84,000–273,000	EUR 12.7–41.4 million
Elevated (medium)	Communities near chemical plants, etc. with PFAS in drinking water	All-cause mortality	621,000	EUR 2.1– 2.4 billion	12.5 million	EUR 41–49 billion
		Low birth weight	8,843 births	136 births of low weight	156,344 births	3,354 births of low weight
		Infection	45,000 children	84,000 additional days of fever	785,000 children	1,500,000 additional days of fever
Background (low)	Adults in general population (exposed via consumer products, background levels)	Hypertension	10.3 million	EUR 0.7– 2.2 billion	207.8 million	EUR 10.7–35 billion
Totals			*Nordic countries*	*EUR 2.8–4.6 billion*	*All EEA countries*	*EUR 52–84 billion*

Some overlap occurs in the figures above, because workers and affected communities are also exposed to background levels of PFAS. At the same time, these costs are likely to be underestimates due to the lack of epidemiological-based risk relationships for calculating other health endpoints and related costs.

Non-health (environment-related) costs to society

The second methodology compiled information on direct costs incurred by communities taking measures to reduce PFAS exposure through remediation of drinking water. Based on these direct costs, ranges of costs per persons affected or per case were developed. These unit costs then became the foundation for aggregating the costs of remediation when environmental contamination, e.g., PFAS concentrations in drinking water, reach certain levels. It should be noted that the ranges are broad, even when normalized against population.

The approach to derive ranges for the mean is dependent on the amount of data available. For the costs of water treatment, for example, several estimates were available, and in such cases it is unlikely that the true mean will be at either extreme of the range from the studies. Therefore, it is reasonable to truncate the observed range, for example by removing estimates that are sufficiently removed from other data as to be considered outliers. For some costs, however, very few estimates are available, each of which may be equally valid for representation of the average: in such a case the observed range in values is adopted as the range of plausible mean values.

Where no range is available from the studied literature, a range has been estimated. For example, the range of +/-90% is used for establishing a health assessment regime (here considered as a non-health cost as it deals with management of the problem, rather than impacts on the health of society). In this example, the range is extremely broad for two reasons, first because of the lack of data available and second because of the potential for variation in the implementation of a health assessment programme.

As with the health-based estimates, the study assumes that 3% of the European population is exposed to drinking water with PFAS concentrations over regulatory action levels, such that the water treatment works serving them will require upgrading and maintenance over the next 20 years. The assumption of 20 years reflects potential for remediation to resolve problems perhaps through decontamination or the use of alternative supplies, or the potential for remedial action to persist for many years. Recognising the uncertainties that exist in the analysis and the available data, costs of remediation have been quantified using a scenario-based approach. For each scenario a number of parameters are specified, relating for example to the size of the affected population and the duration of maintenance works.

Table 2 shows the range of costs for the various categories of actions related to environmental remediation.

Table 2: Summary of estimates of mean cost data for non-health expenditures, 20 years

Action taken when PFAS found	Unit	Best estimate	Range from studies	Adopted range
Monitoring – checks for contamination due to industrial or AFFF use	Cost per water sample tested	EUR 340	EUR 278–402	EUR 278–402
	Cost/case of contamination	EUR 50,000	EUR 5,200–5.8 million	EUR 25,000–500,000
Health assessment (including biomonitoring)	Cost/person	EUR 50	No range	EUR 5–95 (+/-90%)
	Total biomonitoring and health assessment per case where considered appropriate	EUR 3.4 million	EUR 2.5 million–4.3 million	EUR 1 million–5 million
Provision of temporary uncontaminated supply	Cost/person	No relevant data		
Provision of a new pipeline	Cost/person	EUR 800	EUR 37–5,000	EUR 100–1,500
Upgrading water treatment works (capital)	Cost/person	EUR 300	EUR 8–2,200	EUR 18–600
Upgrading water treatment works (maintenance)	Cost/person	EUR 19	EUR 8–30	EUR 8–30
Excavation and treatment of soils – contamination from industrial or AFFF use	Cost/kg PFAS	EUR 280,000	EUR 100,000–4.3 million	EUR 100,000–1 million
	Cost/case	EUR 5 million	EUR 100,000–3 billion	EUR 300,000–50 million

In Table 3 the range of costs for the various categories of actions related to environmental remediation for the five Nordic countries are shown. The overall range of costs is EUR 46 million – 11 billion.

Table 3: Detailed breakdown of ranges for non-health costs to the Nordic countries, assuming that 1 to 5% (best estimate 3%) of the population is exposed above a statutory limit and that water treatment is required over a 20 year period

	N people affected (3%)	Screening and monitoring	Health assessment	Upgrade treatment works and maintenance	Soil remediation	Total
Denmark	170,000	EUR 70,000–8.3 million	EUR 280,000–27 million	EUR 7.4 million–274 million	EUR 0–798 million	EUR 8 million–1.1 billion
Finland	160,000	EUR 250,000–22 million	EUR 270,000–26 million	EUR 7.2 million–265 million	EUR 2.2 million–2.1 billion	EUR 10 million–2.4 billion
Iceland	10,000	EUR 10,000–900,000	EUR 20,000–1.6 million	EUR 400,000–1.6 million	EUR 100,000–86 million	EUR 1 million–105 million
Norway	160,000	EUR 170,000–20 million	EUR 260,000–25 million	EUR 6.8 million–250 million	EUR 1.6 million–1.9 billion	EUR 9 million–2.2 billion
Sweden	290,000	EUR 480,000–47 million	EUR 490,000–46 million	EUR 13 million–472 million	EUR 4.3 million–4.5 billion	EUR 18 million–5.1 billion
Nordic total	*790,000*					*EUR 46 million–11 billion*

The cost estimates provided in the table are likely to be more robust at the aggregate, European level than at the national level.

Table 4 provides aggregated costs covering environmental screening, monitoring (where contamination is found), water treatment, soil remediation and health assessment for the five Nordic countries and for the other EEA countries and Switzerland.

Table 4: Aggregated costs covering environmental screening, monitoring where contamination is found, water treatment, soil remediation and health assessment

	Best estimate	Low	High
Denmark	EUR 145 million	EUR 8 million	EUR 1.1 billion
Finland	EUR 214 million	EUR 10 million	EUR 2.4 billion
Iceland	EUR 12 million	EUR 1 million	EUR 105 million
Norway	EUR 194 million	EUR 9 million	EUR 2.2 billion
Sweden	EUR 423 million	EUR 18 million	EUR 5.1 billion
Other EEA+CH	EUR 15,9 billion	EUR 776 million	EUR 159.9 billion
Total	EUR 16.9 billion	EUR 821 million	EUR 170.8 billion

Parallel calculations for all 31 EEA Member Countries and Switzerland arrive at a range of costs for environmental remediation totalling EUR 821 million to EUR 170 billion. The lower and upper bounds should be considered illustrative because of the limited information available. However, based on the literature review, there is a firm basis for concluding that the lower bound estimates would be exceeded. A best estimate in the order of EUR 10–20 billion is certainly plausible. The potential for higher costs is also possible: An estimate of the costs for one case identified in the course of the research, concerning the town of Rastatt in Baden-Wurttemberg in Germany is in the range of EUR 1 to 3 billion, with the estimated extent of the problem being seen to increase over time. The source of contamination in this case is understood to be contaminated waste paper materials that were spread on agricultural land, demonstrating that serious problems are not always linked to airfields and PFAS manufacture.

A number of other costs related to PFAS contamination are outside the scope of the quantification carried out in this report. These include loss of property value, reputational damage to a polluting company, ecological damage and the costs incurred by public authorities in responding to affected communities – including public outreach, surveys of contamination and remedial measures.

Abbreviations used

6:2 FTS	6:2 Fluorotelomer sulfonate
AFFF	Aqueous film-forming foam (also aqueous firefighting foam)
ATSDR	US Agency for Toxic Substances and Disease Register
BB/CC	Beauty (or Blemish) Balm / Colour Corrector
CA DTSC	California Department of Toxic Substances Control
CAS	Chemical Abstracts Service
CLH	Harmonised classification and labelling
CLP	Classification, labelling and packaging or Regulation (EC) No 1272/2008 on the classification, labelling and packaging of substances and mixtures
CMR	Carcinogenic, mutagenic and toxic for reproduction
C8	Alternative name for PFOA (due to its eight carbon atoms)
D4/D5	Octamethylcyclotetrasiloxane (D4); decamethylcyclopentasiloxane (D5)
DALY	Disability-adjusted life year
DW	Drinking water
ECHA	European Chemicals Agency
EDC	Endocrine disrupting chemical/s
EEA	European Economic Area countries
EFSA	European Food Safety Authority
EFTA	European Free Trade Agreement
E-PRTR	European Pollutant Release and Transfer Registry
EU	European Union
EUR	Official currency for 19 of the 28 members of the European Union (EU)
FCM	Food contact material
GAC	Granular activated carbon
GenX	Replacement for PFOA
GHS	Globally Harmonized System of Classification and Labelling of Chemicals
HFC	Highly Fluorinated Chemical
KEMI	Swedish Chemicals Agency
MCL	Maximum contaminant level
MS	Member State
NATO	North Atlantic Treaty Organization
NGO	Non-governmental organization
NHANES	National Health and Nutrition Examination Survey (US)
NOx	Nitrogen oxide

NO_2	Nitrogen dioxide
OECD	Organisation for Economic Co-operation and Development
PBT	Persistent, bioaccumulative and toxic
PFAS or PFASs	Per- and polyfluoroalkyl substances
PFBA	Perfluorobutanoic acid
PFBS	Perfluorobutane sulfonic acid
PFCAs	Perfluorinated carboxylic acids
PFCs	Perfluorinated compounds
PFDA	Perfluorodecanoic acid
PFDeA	Perfluorodecanoic acid
PFDoDA	Perfluorododecanoic acid
PFNA	Perfluorononanoic acid
PFHpA	Perfluoroheptanoic acid
PFHpS	Perfluoroheptane sulfonic acid
PFHxA	Perfluorohexanoic acid
PFHxS	Perfluorohexane sulfonic acid
PFHxSF	Perfluorohexane sulfonyl fluoride
PFOA	Perfluorooctanoic acid
PFOS	Perfluorooctane sulfonic acid
PFPE	Perfluoropolyether
PFPeA	Perfluoropentanoic acid
PFSAs	Perfluoroalkane sulfonates
PFTDA	Perfluorotetradecanoic acid
PFTrDA	Perfluorotridecanoic acid
PFUnDA	Perfluoroundecanoic acid
PM	Particulate matter
POPs	Persistent Organic Pollutants
POSF	Perfluorooctane sulfonyl fluoride
PPP	Purchasing power parity
PTFE	Polytetrafluoroethylene (Teflon)
PVDF	Polyvinylidene fluoride
RAC	Risk Assessment Committee (under REACH)
REACH	Regulation (EC) No 1907/2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals
RIVM	Dutch National Institute for Public Health and the Environment
RME	Risk management evaluation
SEAC	Socio-Economic Assessment Committee (under REACH)
SEK	Swedish krona
SMEs	Small and Medium Enterprises
SMR	Standardized mortality ratio
SOx	Sulphur oxide
SO_2	Sulphur dioxide
SVHC	Substances of very high concern
TDI	Tolerable daily intake

TOF	Total organic fluorine
UBA	German Federal Environmental Agency (Umweltbundesamt)
UNEP	United Nations Environment Programme
USD	United States Dollar
USEPA	US Environmental Protection Agency
USFAA	US Federal Aviation Agency
USFDA	US Food and Drug Administration
VAT	Value-added tax
VOCs	Volatile organic compounds
vP	Very persistent
vPvB	Very persistent, very bio-accumulative
WHO	World Health Organization
WTP	Willingness to pay
WWTP	Wastewater treatment plant

1. Introduction

Per- and polyfluoroalkyl substances (PFAS) are a large group of chemical compounds that have been used in a wide range of commercial products since the 1950s. They are now found in the environment all around the world. Most people in industrialised countries have one or more PFAS in their blood.

PFAS are highly persistent. Though some PFAS may partially degrade under environmental conditions, they will all eventually transform into highly stable end products that will remain in the environment for hundreds or thousands of years[2], such that human and environmental exposure will continue long into the future. Human epidemiological studies have found associations between exposure to PFAS and hepatocellular damage affecting liver function in adults, obesogenic effects in females, kidney cancer, low birthweight, reduced length of gestation, and reduced immune response to routine childhood immunizations.[3]

Because of their persistence, PFAS can travel long distances and have been found even in remote regions such as the high Himalayas and the Arctic where no direct sources of PFAS are known. The compound PFOA, for example, has been found in top predators such as polar bears.[4] Moreover, the PFAS tend to be highly mobile and to move readily into ground and surface waters once released to the environment.

In the 1950s, when highly fluorinated compounds were first commercialised, the focus was on long-chain PFAS – the so-called C8 substances used in the manufacture of Teflon-coated cookware, water- and stain-resistant textiles, and fire-fighting foams. Evidence emerged in the 1980s and 1990s of the toxicity and bio-accumulability of the long-chain PFAS, such as PFOS and PFOA. These long-chain surfactants have been well-studied and are now regulated in different parts of the world to varying extent, leading to complete or partial phase-outs in the EU and the USA. However, PFOA and its derivatives continue to be manufactured in China, India and Russia and as of 2017, China was reported to be the only known manufacturer of PFOS and its derivatives.[5] Despite being heavily restricted, these substances are still detected in some consumer products (see section 4.4.3 of this report concerning cosmetics), and other long-chain PFAS continue to be manufactured and used. Some producers have replaced the C8s with short-chain homologues – the C6s and C4s; they claim that the short-chain PFAS are "safer" in

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[2] Wang Z *et al.* (2017) A never-ending story of per- and polyfluoroalkyl substances (PFASs)?. Environmental Science & Technology, Mar 7;51 (5). pp 2508–2518.

[3] Grandjean P *et al.* (2014). Changing interpretation of human health risks from perfluorinated compounds. Public health reports, vol. 129: (6). pp. 482–485.

[4] Vierke L *et al.* (2012). Perfluorooctanic acid (PFOA) – main concerns and regulatory developments in Europe from an environmental point of view. Environmental Sciences Europe. v 24: (16).

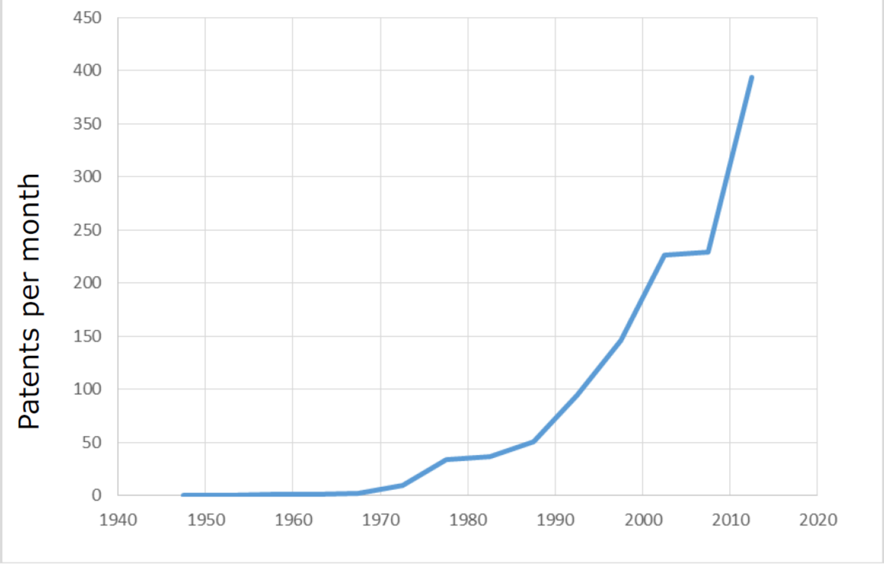
[5] Interstate Technology Regulatory Council (2017). History and use of per- and polyfluoroalkyl substances.

that they are not as bioaccumulative as the long-chain PFAS. In the meantime, evidence is emerging that the short-chain alternatives pose similar risks to human health.[6]

Moreover, the number of different PFAS on the global market keeps growing. A 2015 study reported more than 3,000 PFAS were on the global market for commercial use.[7] This number was updated in 2018 by a search carried out for the OECD which found over 4,700 different CAS numbers for perfluorinated compounds.[8] Other compounds may also be under production, but their identities are protected for confidential business reasons.

The number of possible applications of PFAS are also growing rapidly. Figure 1 shows an increasing trend in the number of patents with "perfluor" in the patent text that are approved in the USA each month.[9]

Figure 1: Number of approved patents in US with "perfluor" in the patent text



Source Fischer, S., 2017. "Known uses of PFAS", presentation at Nordic workshop on joint strategies for PFAS, 5.04.2017.

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[6] Kotthoff M *et al.* (2015). Perfluoroalkyl and polyfluoroalkyl substances in consumer products. Environmental Science and Pollution Research International. 22(19): 14546–14559.

[7] Swedish Chemicals Agency (2015). Occurrence and use of highly fluorinated substances and alternatives: Report from a government assignment.

[8] For a list of 4,730 PFAS-related CAS numbers compiled from publicly accessible sources of information, see OECD (2018). Toward a new comprehensive global database of per and polyfluoroalkyl substances (PFASs): summary report on updating the OECD 2007 list of per and polyfluoroalkyl substances (PFASs).

[9] Swedish Chemicals Agency (2015). Occurrence and use of highly fluorinated substances and alternatives: Report from a government assignment. Report 7/15.

A large proportion of these compounds are polymers and therefore exempted from registration requirements under the EU REACH Regulation[10]; of the others only a few are registered. Very little information is available on quantities produced and for half of all PFAS, almost no information can be found concerning their uses.

The quantities of PFAS produced globally also keeps growing. Fluorotelomers used primarily in aqueous firefighting foams (AFFFs), in textiles to provide stain resistance and surface finishing, and as surfactants are a major component of the market. A recent market research report estimated that production of fluorotelomers globally will grow from approximately 21,030,000 kg in 2013 to 47,800,000 kg by 2020, for a 2020 value of USD 539.3 million (EUR 466 million).[11] The main drivers of growth are an increased demand from the textile sector (34.8% of total demand in 2013) and government norms leading to use of AFFFs in firefighting systems.

Today, PFAS are found in cosmetics, food contact materials, inks, medical devices, mobile phones, pharmaceuticals and textiles. They are used in pesticide formulations, metal production, oil production and mining. They are capable of long-range transport, are highly mobile, and constitute a severe threat to clean water supplies around the globe.

The long-term socioeconomic costs of the PFAS already in products or released to the environment are poorly understood. PFAS released over the course of a product's lifecycle will remain in the natural and man-made environments for an indefinite time. One of the concerns is that the contamination may be poorly reversible or even irreversible, and may reach levels that could render natural resources such as soil and water unusable far into the future. This could result in continuous exposure and unavoidable harmful health effects, particularly for vulnerable populations, such as children. For example, PFOS in firefighting foams applied during the 2005 Buncefield explosion contaminated an aquifer that is an important public drinking water source for the Greater London area, so that it is no longer available as a water supply.[12]

Consensus statements from leading scientists studying PFAS, i.e., the Helsingør Statement[13], the Madrid Statement[14], and the Zurich Statement[15] highlight the health and environmental risks posed by the highly fluorinated chemicals as a group. The statements emphasize the extreme persistence of the carbon-fluorine bond in nature and call for regulatory as well as non-regulatory actions to address the risks associated with all highly fluorinated chemicals, including the short-chain PFAS.

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[10] Commission Regulation (EU) No 1907/2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH), establishing a European Chemicals Agency, amending Directive 1999/45/EC and repealing Council Regulation (EEC) No 793/93 and Commission Regulation (EC) No 1488/94 as well as Council Directive 76/769/EEC and Commission Directives 91/155/EEC, 93/67/EEC, 93/105/EC and 2000/21/EC. ("REACH Regulation"), O.J. 396, 30.12.2006, p. 1.

[11] Press release, Fluorotelomers Market to Reach USD 539.3 Million Worldwide by 2020, Digital Journal. Accessed 10.11.2018.

[12] Matt Gable, UK Environment Agency, as cited in IPEN (2018). Fluorine-free firefighting foams (3f) viable alternatives to fluorinated aqueous film-forming foams (AFFF).

[13] Scheringer M *et al.* (2014). Helsingør Statement on poly- and perfluorinated alkyl substances (PFASs)', Chemosphere, vol. 114. pp. 337–339.

[14] Blum A *et al.* (2015). The Madrid Statement on Poly- and Perfluoroalkyl Substances (PFASs). Environmental health perspectives. Vol. 123, no. 5. pp. A107–11.

[15] Ritscher A *et al.* (2018). Zürich Statement on Future Actions on Per- and Polyfluoroalkyl Substances (PFASs), Environmental Health Perspectives, vol. 126, no 8.

This study looks at how the production of PFAS, manufacture and use of PFAS-containing products, and end-of-life disposal of PFAS has resulted in widespread environmental contamination and human exposure, resulting in significant socioeconomic costs. It sets forth a methodological framework for estimating costs for society related to negative impacts on the environment and human health, including health-related costs and costs for remediation, and uses case studies to illustrate the main impact pathways from PFAS releases and to gather information on direct costs incurred by society to date to reduce exposure to PFAS.

The focus of the study is on the costs of inaction in the countries comprising the European Economic Area (EEA). It uses data specific to Nordic countries when available, but also draws cost data from other European countries, the USA and Australia, where relevant. The scope is C4-14 non-polymer fluorosurfactants.

It is important to remember that the burden of PFAS-related costs such as health-related and remediation costs is largely shouldered by governments and the citizens who pay taxes, while the pollution partly is caused by private operators. By compiling information on societal costs related to PFAS, it is hoped that this study will bring about more effective and cost-efficient management of the risks posed by PFAS.

2. The regulatory framework as baseline in relation to PFAS

For the purposes of this study, we are defining the "cost of inaction" as the costs to society from existing and future exposures to PFAS if no further measures to curb such exposures are taken. The term "further measures" could refer to additional policy measures as well as better enforcement and implementation of existing policies and regulations.[16] The case studies and other information collected for this study are intended to provide an overview of the baseline with respect to PFAS exposure.

The aim is dual: (1) to establish a framework for estimating costs for society due to negative impacts on human health and the environment related to PFAS exposure; and (2) to provide monetary values for the costs borne by society, by using costs derived from actual cases involving health impacts or where remedial measures were taken to address PFAS contamination. The overall intention is to highlight the economic case for taking effective and timely action to manage the risks of negative impacts from PFAS exposure.

Costs of inaction may refer to different things. One type of cost is related to staying within regulatory guidelines for drinking water (see the subsection below). For example, cases where drinking water supplies were contaminated have led to costs ranging from replacement of water supplies (bottled water, drilling of new wells) to removal of the PFAS contamination from the drinking water by further treatment (reverse osmosis, activated charcoal filters) before delivery to consumers.

Another type of cost is the health-related expenses incurred by people exposed to PFAS and suffering from negative health effects as a result. Cases where human populations have been exposed to PFAS over time have been linked to a number of adverse health effects, leading to greater health care costs, loss of production due to absence from work or lower productivity, and a lower quality of life.

Less tangible costs might be the loss of use of a natural resource such as groundwater or the loss of property value for homeowners in affected areas. The extreme persistence and mobility in the environment of PFAS is also a consideration, since PFAS contamination tends to continue to spread and costs of clean up through remediation of soil or water will increase if actions are delayed.

In recent years, other studies have aimed to estimate costs of inaction related to chemicals exposure. A 2013 UNEP study on costs of inaction on the sound management of chemicals.[17]looked at available literature concerning environmental and health costs

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[16] The OECD defines inaction as the lack of development of "no new policies beyond those which currently exist". See OECD. (2008). Environmental Outlook to 2030. Chapter 18: "Chemicals".

[17] UNEP (2013). Cost of inaction on the sound management of chemicals. Report Number: DTI/1551/GE.

linked to a wide range of chemical effects, including heavy metals (mercury, lead), outdoor pollutants (NOx, NO_2, PM, SOx, SO_2, VOCs), pharmaceuticals and pesticides. Based on data available it is estimated that accumulated health costs related to pesticide poisonings in Sub-Saharan Africa will reach around USD 97 billion by 2020.

The 2014 study for the Nordic Council on costs linked to effects of endocrine disrupting substances on male reproductive health is more focused. It reviewed the strength of the evidence regarding negative effects of chemicals considered endocrine disruptors and estimated numbers of incidences of negative effects as well as related costs to society.[18] It equated costs of illness with the economic value of reducing risks of exposure to endocrine disruptors. A theme in both studies is the lack of data concerning numbers of chemical exposures and related costs.

2.1 Guideline values for protection of health related to PFAS exposure

For the purpose of estimating costs of inaction, it is important to note when levels of contamination require remedial action. Among the tools used by regulatory authorities to control pollutants in environmental media such as groundwater and soil or in water or food for human consumption are limit or guideline values. Such values are important for determining when contamination is at levels that pose unacceptable risks to human health or the environment so that (1) action to remediate the resource is required; and (2) restriction of a certain use or substance is needed to prevent further contamination.

Guideline values for acceptable concentrations of PFAS in drinking water are currently in flux. Recent analyses of epidemiological evidence, including of immunotoxicological impairment at background levels of exposure to PFAS[19], have led to several regulatory authorities issuing opinions suggesting recommended concentration levels be lower than levels set previously.

Most limit values or guidelines to date are for individual long-chain PFAS (PFOS, PFOA, PFHxS, due to their known toxicity and bioaccumulability, e.g., the 2015 World Health Organization recommendation of 0.4 µg/l (400 ng/l) for PFOS and 4 µg/l (400 ng/l) for PFOA in drinking water.

More recent guidelines recognise the potential for harmful impacts from groupings of PFAS, including the short-chain PFAS. This is reflected in the group parameter for PFAS proposed in February 2018 for revision of Council Directive 98/83/EC on the quality of water intended for human consumption (Drinking Water Directive).[20] The Commission proposal suggests regulating the whole class of PFAS, i.e., values of

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[18] Nordic Council of Ministers (2014). The Cost of Inaction – a socioeconomic analysis of costs linked to effects of endocrine disrupting substances on male reproductive health. TemaNord 2014:557.

[19] Grandjean P (2018). Delayed discovery, dissemination, and decisions on intervention in environmental health: a case study on immunotoxicity of perfluorinated alkylate substances. Environmental Health (2018) 17:62.

[20] Proposal for a Directive of the European Parliament and of the Council on the quality of water intended for human consumption COM/2017/0753 final - 2017/0332 (COD).

0.1 µg/l (100 ng/l) for individual PFAS and 0.5 µg/l (500 ng/l) for PFAS as a group.[21] This is an approach already used for pesticides in drinking water.

The limit values for PFAS in drinking water set by Sweden and Denmark are also parameters for groups of PFAS. The Swedish National Food Agency has set a group limit value for PFAS at 90 ng/l.[22] This also serves as an action level. If the sum of 11 PFAS in drinking water exceeds that level, action is to be taken as soon as possible to reduce the PFAS to concentrations as low as practically possible below that action level. Denmark applies a limit value of 100 ng/l for the sum of 12 PFAS in drinking water (the parameter for PFAS in soil is 0.4 mg/kg TS).[23]

Germany's Federal Umweltbundesamt (UBA) first published recommended values in 2006 based on a request by the Hochsauerla Valley (see Case Study 3.5.2.2). Since then, new data has led to further revisions and the nd Public Health Department prompted by the PFAS contamination incident in Moehne current UBA guidelines set the lifelong precautionary value at 100 ng/l per se for PFOA and PFOS and 300 when both are present.[24]

In December 2018, European Food Safety Authority (EFSA) published a scientific opinion on health risks related to PFOS and PFOA in the food chain.[25] A previous opinion issued in 2008 set values for tolerable daily intake (TDI) of PFOS at 150 ng/kg bw/day and for PFOA at 1500 ng/kg bw/day. This has been calculated as equivalent to limit values of 70 ng/l for PFOS and 700 ng/l for PFOA.

The most recent EFSA opinion sets tolerable daily intake (TDI) for PFOS in food at 13 ng/kg bw/week and for PFOA at 6 ng/kg bw/week.[26] This has been calculated as equivalent to limit values of 6.5 ng/l for PFOS and 3 ng/l for PFOA[27] which enables the values to be compared to those set for drinking water.

In the USA, guideline values are also undergoing revision. In 2016 the US Environmental Protection Agency issued a lifetime drinking water health advisory that set limit values for PFOA at 70 ng/l and for PFOS also at 70 ng/l.[28] The advisory notes that when these two chemicals co-occur in a drinking water source, a conservative and health-protective approach would be to set the sum of the concentrations ([PFOA] + [PFOS]) at 70 ng/l.

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[21] The Commission's explanatory document points out that these values exceed those referred to in Sweden or the USA and therefore compliance should be feasible.

[22] Swedish National Food Agency (2017). Riskhantering - PFASs i dricksvatten och fisk.

[23] Danish Environmental Protection Agency (2015). Perfluorerede alkylsyreforbindelser (PFAS-forbindelser) incl. PFOA, PFOS og PFOSA.

[24] German Environment Agency (2017). Fortschreibung der vorläufigen Bewertung von per- und polyfluorierten Chemikalien (PFC) im Trinkwasser and German Environment Agency (2011). Grenzwerte, Leitwerte, Orientierungswerte, Maßnahmenwerte Aktuelle Definitionen und Höchstwerte.

[25] EFSA Panel on Contaminants in the Food Chain), Knutsen HK *et al.*, 2018. Scientific opinion on the risk to human health related to the presence of perfluorooctane sulfonic acid and perfluorooctanoic acid in food. EFSA Journal 16(12):5194. DOI: https://doi.org/10.2903/j.efsa.2018.5194

[26] From the 2018 EFSA draft abstract on human epidemiological studies. The panel noted that *for both compounds exposure of a considerable proportion of the population exceeds the proposed TWIs*.

[27] Grandjean P (2018). Delayed discovery, dissemination, and decisions on intervention in environmental health: a case study on immunotoxicity of perfluorinated alkylate substances. Environmental Health (2018) 17:62.

[28] Environment Protection Agency (2016). Fact Sheet PFOA& PFOS Drinking Water Health Advisories.

In 2018, the US Agency for Toxic Substances & Disease Register (ATSDR) issued a draft toxicological profile for perfluoroalkyls.[29] The draft profile suggested provisional minimal risk levels (MRLs) of 7 ng/l for PFOS and 11 ng/l for PFOA – parameters that are seven to ten times lower than the lifetime advisory levels set by USEPA.

Table 5: Regulatory parameters for PFAS in drinking water (DW) (ng/l)

Standard	PFOS	PFOA	PFNA	PFAS (single)	PFAS (group)
WHO guidelines for drinking water (2015)	40	400			
Sweden NFA action level (sum of 11 PFAS, 2014)					90
Denmark (sum of 12 PFAS, 2015)					100[1]
Germany (2017)	100	100	60		300[2]; 7,000[3]
EU proposed level single PFAS in DW (2018)				100	
EU proposed level total PFAS in DW (2018)					500
EFSA TDI in food (2008)	70	700			
Draft EFSA TDI in food (2018)[4]	6.5	3			
US EPA lifetime DW health advisory (2016)	70	70			70
US ATSDR draft finding (2018)	7	11			
State of New Jersey (2018)	13	14	13 (binding)		70
State of Minnesota (2017)	27	35			

Note: 1) Sum of 12 PFAS.
2) PFOS+PFOA.
3) PFAS except PFOS and PFOA.

Source: Estimated. Grandjean P (2018). Delayed discovery, dissemination, and decisions on intervention in environmental health: a case study on immunotoxicity of perfluorinated alkylate substances. Environmental Health (2018) 17:62.

Several individual US states are setting parameters for PFAS in drinking water at even more stringent levels. In July 2018, the US state of New Jersey adopted a maximum contaminant level (MCL) for perfluorononanoic acid (PFNA) of 0.013 µg/l (13 ng/l).[30] It is considering the recommendation of the New Jersey Drinking Water Quality Institute to set an MCL for PFOS at 0.014 µg/l (14 ng/l). Likewise, the state of Minnesota decided in 2017 to update their health values basing them on the vulnerability of foetuses and infants who are exposed via their mothers, rendering the values significantly lower than those set by the federal USEPA (see Table 5).[31]

The lowering of mandatory and advisory levels for PFAS in drinking water indicate a growing awareness that exposure to PFAS even at low levels can have negative impacts on human health. In particular, studies have found impaired immunological responses to vaccines at levels of exposure as low as 1 ng/l in serum – levels that are exceeded in most humans.[32]

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[29] Agency for Toxic Substances and Disease Registry (2018). Draft toxicological profile for perfluoroalkyls.

[30] New Jersey Register, Adopted Amendments: N.J.A.C. 7:9E-2.1; 7:10–5.2, 5.3, and 12.30; and 7:18–6.4.

[31] Minnesota Department of Health Perfluoroalkyl Substances (PFAS). Accessed 09.10. 2018.

[32] Grandjean P (2018). Delayed discovery, dissemination, and decisions on intervention in environmental health: a case study on immunotoxicity of perfluorinated alkylate substances. Environmental Health (2018) 17:62.

As the proposal for revision of the EU Drinking Water Directive notes, these substances do not belong in the environment. The proposal points out that Directive 2008/105/EC on environmental quality standards in the field of water policy sets a limit value of 0.65 ng/l for PFOS and suggests a precautionary approach as the way forward.

Given that these regulatory parameters are currently a moving target, this study proposes to use Sweden's action level of 90 ng/l as the point of comparison in considering when a resource is considered contaminated by PFAS, such that remedial action should be taken.

2.2 Other regulatory actions underway

Other regulatory efforts underway are aimed at controlling PFAS on the market, because of evidence of their negative impacts. Within the European Economic Area (EEA), member countries are subject to the provisions of the EU REACH Regulation, as well as to the regulation implementing the Stockholm Convention on persistent organic pollutants.

PFOS has been restricted under the Stockholm Convention since 2009. During the fall of 2014, Norway and Germany joined in submitting a proposal for the EU to restrict PFOA, its salts and related substances.[33] This led to the adoption of Commission Regulation (EU) 2017/1000 of 13 June 2017 amending Annex XVII to REACH, as regards perfluorooctanoic acid (PFOA), its salts and PFOA-related substances.

In March 2017, Sweden and Germany proposed to consider PFHxS a substance of very high concern.[34] This was adopted by the European Chemicals Agency (ECHA) later the same year, and the substance is now on the Candidate List. Norway has registered an intention to submit a restriction proposal for PFHxS under REACH.

Sweden and Germany also jointly proposed in 2017 to restrict the manufacturing and placing on the market of six PFAS (PFNA, PFDA, PFUnDA, PFDoDA, PFTrDA and PFTeDA), as well as their salts and precursors.[35] The aim in restricting these long-chain (C9-C14) PFAS is to prevent industry from switching to them once the restriction of PFOA goes into effect in 2020. Both the RAC (Risk Assessment Committee) and the SEAC (Committee for Socio-economic Analysis) have agreed to the restriction proposal; public consultation on the SEAC opinion closed on 19 November 2018.

The Stockholm Convention on persistent organic pollutants (POPs) continues to consider measures related to PFAS additional to the 2009 listing of PFOA for global restriction (Annex B). In September 2018, the POPs Review Committee agreed to recommend to the Parties to the Convention that PFOA be phased out, because its PBT qualities, the occurrence of PFOA in environmental compartments, and the evidence of long-range environmental transport supported the conclusion that it is likely to lead to significant adverse effects such that global action is warranted. It also evaluated the

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[33] ECHA (2014). Germany and Norway propose a restriction on Perfluorooctanoic acid (PFOA), its salts and PFOA related substances.

[34] ECHA (2017a). Inclusion of substances of very high concern in the Candidate List for eventual inclusion in Annex XIV.

[35] ECHA (2017b). Public consultation. Germany, in collaboration with Sweden, proposed a restriction on C9-C14 perfluorocarboxylic acids (PFCAS), their salts and related substances (precursors).

exempted uses of PFOS based on the availability of alternatives and recommended most of them for removal or to be made time-restricted. The POPs Review Committee also adopted the risk profile for PFHxS, thereby moving it to the next stage of a risk management evaluation (part of the process for considering whether to list a chemical in the Convention).[36] The next meeting of the Parties takes place in April 2019 when the decisions will be taken on the table concerning the listing of PFOA for global phase-out and for removing exemptions for uses of PFOS.

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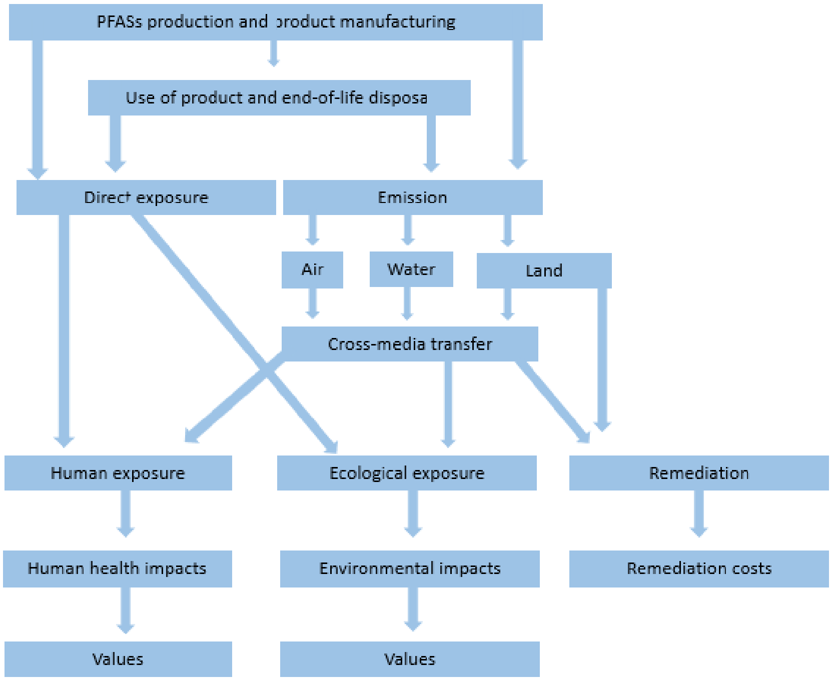
[36] Stockholm Convention (Website) Report of the POPs Review Committee at the work of its fourteenth meeting, UNEP/POPS/POPRC.14/6.

3. Methodology to assess environment and health-related costs

This chapter describes the methodology for building an integrated socioeconomic model to assess the environmental and health-related costs of PFAS exposure in European countries. No such methodology had been developed at the time this study was conducted. In a stocktake of socioeconomic assessments for PFOA and its salts carried out for the OECD[37], the need for a method to draw together information on the long-term environmental and health costs related to PFAS exposure was expressed.

The impact pathway shown in Figure 2 provides an overall framework for the socioeconomic analysis.

Figure 2: Generic impact pathways for linking substances to possible impacts



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[37] Gabbert, S. (2018). Economic assessments and valuations of environmental and health impacts caused by Perfluorooctanoic acid (PFOA) and its salts. OECD Environment Working Paper No 128.

The figure links production and use of PFAS to impacts and their economic valuation. It provides a template for assessment of each source, enabling the analyst to consider which impacts are relevant in a case.

Following on from Figure 2, data needs for the assessment are identified in Table 6, which presents an overview of the socioeconomic assessment method that guided the analysis. The method defines six stages for the assessment of both health and environmental impacts. For each stage, it defines a set of input parameters, data sources and key assumptions by stage of the assessment process. The evidence available on the extent of PFAS exposure and its impact is often restricted to a case of contamination in a specific geographic area. One of the key assumptions noted for several stages is therefore the transferability of scientific findings from one specific context to another.

Table 6: Assessing the socio-economic impacts of PFAS exposure

Stage	Input parameters	Data sources	Key assumptions
Defining sources of PFAS exposure	Uses of PFAS, e.g., production, product manufacture, product use	Scientific and grey literature, on-line research	Future applications
	Number of activities involving PFAS (by use)	Case studies	Future use, alternatives
	Identification of impact pathways (by use)	Case studies	Assumptions of future conformance
Identification of impacts	Health impacts Listing of impacts linked to PFAS, e.g. cancers Environmental impacts Contamination of resources such as drinking water	Case studies and scientific literature	Causality for PFAS in general and then for specific PFAS
Quantification of impacts	For each effect identified above: Size of population or receiving body at risk Prevalence of disease Response function	National (etc.) statistics, scientific literature, including reviews	Transferability
Valuation	Health Unit values e.g. EUR/death	Documents submitted to ECHA, OECD, etc. Further review of the literature	Transferability
	Environment Willingness to pay to avoid loss of ecosystem services Cost of damage to commercial fisheries, agriculture, etc. Cost of environmental remediation	Documents submitted to ECHA. OECD, etc. (eg. D4/D5 dossier) Further review of the literature. Market prices Published case study materials	Transferability
Value transfer	Factors including exchange rates, size of population affected and income levels to improve applicability of values to the target population	Valuation literature, exchange rate databases	Range of factors that should be accounted for
	Discount rates	Standard European Commission practice (constant 4%) + alternatives of 0% and 2%	Validity of constant rates over extended timescales
Aggregation	Contextual data permitting quantification of effects beyond the case study materials that are available	National (etc.) statistics, scientific literature, including reviews	Transferability

The specificities of the methodologies for assessing health impacts can be found in Section 5.1 while those for the environmental impacts can be found in Section 5.2.

The lack of systematic and standardised evidence in addition to the underlying uncertainties with regards to the extent of impact and their consequences presented challenges for the process of developing quantitative estimates. The robustness of each quantitative finding is explored through sensitivity analysis. The sensitivity analysis allowed for the construction of lower and upper bounds for each quantitative estimate to reflect the underlying uncertainties. Other costs that could not be quantified, but for which strong evidence was identified, are assessed in a qualitative manner.

3.1 Health-related costs

This section describes the specific methodology for assessing the health-related costs of PFAS exposure. A growing body of scientific literature suggests that PFAS exposure can lead to a wide range of adverse health impacts at different levels of exposure. To date, a monetisation of these health-related costs has not been developed due to the lack of a global consensus on the specific health impacts linked to PFAS exposure and a complete understanding of the level of exposure needed to trigger a health impact. This cost of inaction assessment therefore presents a first attempt to monetise the impacts for several of the identified health endpoints of PFAS exposure.

The methodology takes findings from various epidemiological studies showing relative risks due to exposure. It considers "what-if" scenarios, where scenarios assume the transferability of epidemiological studies from one context to another in some cases, and the subsequent impacts. It then extrapolates those findings to the "exposed" population in the Nordic countries and the EU. The design of these scenarios attempts to reflect the underlying uncertainties with respect to the level of exposure and the epidemiological evidence. The methodology for assessing the health-related costs follows four basic steps: (1) identification of endpoints, (2) responses to levels of exposure, (3) quantifying impacts and (4) aggregation. Each step is described below.

3.1.1 Identification of endpoints

In assessing the potential health impacts of exposure to PFAS, toxicologists and epidemiologists need information on both human health endpoints (which are defined as conditions or diseases that reflect poorer health and an increased risk of mortality) and substance exposure. Data on human health endpoints may be obtained from for example from public health records or from surveys of exposed individuals. The level of human exposure to PFAS can be inferred from e.g. data collected from monitoring PFAS contamination in drinking water or other local sources, or it can be investigated more closely through the analysis of blood samples.

Identifying health impacts related to exposure to PFAS is challenging for several reasons. Health impacts are typically identified through studies that compare a relatively "exposed" group and a relatively "unexposed group" while controlling for other factors related to the health endpoint. From a causal perspective the ideal setting would be a randomized control study (experiment), in which individuals would be assigned at random into treatment and control groups (exposed/unexposed groups). This would ensure random assignment of background characteristics in each group, i.e the background characteristics in each group would on average be the same. However, in settings with environmental pollution or toxic substances, this is neither ethical nor economically feasible.

A potenitial solution to this metodological problem is to look for a "natural experiment" where the exposed group has similar background characteristics as the unexposed group, for example two neighborhoods in close geographic proximity where one is more exposed than the other. However, given the persistence of PFAS and their ability to travel long distances, it is unlikely that a group in close proximity to the contaminated area would not have an elevated level of exposure. In fact, considering that PFAS have been found in some of the most remote places in the world, it may not be possible to find a truly unexposed group among humans.

To further complicate inference, contamination often consists of more than one PFAS compound, making it difficult to attribute the exposure to a single compound. The lack of regular biomonitoring of PFAS in humans (through collection and analysis of blood samples) in many countries also presents a severe limitation in the data available on the health impacts of PFAS at different levels of exposure and in different contexts. In addition, the sample sizes for most epidemiological investigations are quite small, which limits the extent to which health endpoints can be identified with a reasonable level of confidence. This is especially challenging for health endpoints that are relatively uncommon in the general population such as testicular and kidney cancer. In conclusion, the above mentioned reasons may explain why some epidemiological studies find statistically significant effects while others do not.

The first part of Annex 2 presents an overview of epidemiological studies that have linked PFAS exposure with a range of different health endpoints. The sample size, the population studied, and the time period are indicated for each study.

Several regulatory bodies and expert panels around the globe have carried out reviews of the scientific evidence in order to reach conclusions about the relevant health endpoints of human exposure to PFAS. These reviews usually seek a certain level of consensus across different scientific studies in order to conclude that PFAS have an adverse impact on that health endpoint. In drawing conclusions about specific health endpoints, these reviews utilise a "strength of the evidence" approach. The scope of the evidence considered as well as the evaluation of the strength of the evidence varies, however, across the available reviews. This leads to different conclusions in terms of the recognised health endpoints of PFAS (see Table 7).

For example, an Expert Health Panel convened by the Australian Department of Health presented a review of recent literature reviews of the potential health impacts of PFAS in May 2018.[38] The study did not find conclusive evidence for any of the health

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[38] Australia Government Department of Health (2018). Expert Health Panel for Per- and Poly-Fluoroalkyl Substances (PFAS).

endpoints identified in other expert reviews. However, the Panel came to the conclusion that because current evidence is primarily based on weak study designs and is inconsistent in many respects, some degree of important health effects for individuals exposed to PFAS could not be ruled out based on the existing evidence.

The provisional report from the European Food Safety Authority (EFSA) concludes that PFAS exposure can lead to metabolic disease, immunotoxicity, and developmental toxicity, but finds the evidence with respect to cancer and endocrine disruption not sufficiently robust. The draft toxicological profile from the US Agency for Toxic Substances and Disease Registry (ATSDR) on the other hand suggests that the evidence demonstrates a relationship with several health endpoints such as asthma, pregnancy-induced hypertension and an increased risk of thyroid disease. This assessment applies not only for PFOA and PFOS, but also several other PFAS compounds such as PFHxS and PFDeA.

Table 7: Reviews of health endpoints linked to PFAS exposure

Category	Health endpoint	EFSA	ATSDR	C8 Health Project	US EPA	OECD
Metabolic disease	Liver damage	✓ PFOA)	✓ (PFOA, PFOS, PFHxS)		✓ (PFOA)	✓
	Ulcerative colitis			✓		
	Increased serum cholesterol levels	✓ (PFOS, PFOA)	✓ (PFOA, PFOS, PFNA, PFDeA)	✓	✓ (PFOA, PFOS)	
Immuno- toxicity	Decreased immune response (e.g. antibody response to vaccines)	✓ (PFOS)	✓ (PFOA, PFOS, PFHxS, PFDeA)		✓ (PFOA)	✓
	Increased risk of asthma diagnosis		✓(PFOA)			
Endocrine disruption	Increased risk of thyroid disease (elevated hormones)		✓ (PFOA, PFOS)	✓	✓ (PFOA)	✓
	Elevated sex hormones					✓
	Decreased fertility		✓ (PFOA, PFOS)		✓ (PFOS)	
	Pregnancy-induced hypertension/pre-eclampsia		✓ (PFOA, PFOS)	✓	✓ (PFOA)	
	Delayed menstruation and earlier menopause				✓ (PFOA)	
Developmental outcomes	Lower birth weight	✓ (PFOS, PFOA)	✓(PFOA, PFOS)		✓ (PFOS)	✓
Carcinogenicity	Testicular and kidney cancer			✓	✓ (PFOA)	✓

Another key assessment was made by the C8 Health Project, which was established as part of a class action legal settlement made by a chemical manufacturer in West Virginia.[39] The C8 Health Project was led by a Science Panel of three epidemiologists who carried out a series of scientific studies using biomonitoring data gathered from the site.

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[39] The chemical manufacturer was Dupont. In 2017, Dupont merged with the Dow Chemical Company. Dupont is now a subsidiary of the Dow Chemical Company.

The Science Panel concluded that the exposure had a probable link with seven health conditions and diseases: High cholesterol (hypercholesteremia), ulcerative colitis, thyroid function, testicular cancer, kidney cancer, preeclampsia, as well as elevated blood pressure during pregnancy (pregnancy-induced hypertension). These endpoints roughly reflect the health impacts identified in a 2018 review conducted for the OECD of epidemiological research studies.[40] Lastly, the US EPA issued two reports in 2016 for the health effects for PFOA and PFOS.[41] It recognised almost all of the health endpoints identified by other reviews and panels.

Some epidemiological studies were considered as conclusive evidence in support of a certain health endpoint by one assessment, but not as conclusive by another. For example, the EFSA opinion prominently cites a study conducted as part of the C8 Health Project[42] as providing strong evidence that low birthweight is a relevant health endpoint.[43] Yet the C8 Science Panel did not find the evidence sufficiently strong for low birthweight as an endpoint. The lack of consistency across these assessments and the differential weighting of specific epidemiological studies reflects the challenges at present to reach a global consensus on the health endpoints of PFAS contamination.

As per Table 7, the body of scientific evidence and research has grown over time, collectively suggesting that PFAS do have adverse health impacts on humans. A July 2018 study[44] notes that

> "[a]ccumulated evidence from studies of experimental animal models and of humans from highly exposed populations supports the conclusion that PFOA and PFOS, along with other carboxylate and sulfonate PFAS, are multi-system toxicants. In other words, exposure to PFAS is associated with toxicological findings in many types of tissues and systems."

The International Agency for Research on Cancer (IARC) provides additional insights about the carcinogenicity endpoint. The agency published a monograph in June 2018 concluding that there is limited evidence in humans for the carcinogenicity of PFOA. However, a positive association between PFAS exposure and cancers of the testis and the kidney was observed, rendering the overall evaluation that PFOA is possibly carcinogenic to humans.[45]

This cost of inaction assessment of PFAS is built on the assumption that exposure to PFAS is linked to the health endpoints indicated in Table 7. In addition, the assessment assumes that different short- and long-chain PFAS compounds will lead to similar adverse health impacts.

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[40] Gabbert S (2018). Economic assessments and valuations of environmental and health impacts caused by Perfluorooctanoic acid (PFOA) and its salts. OECD Environment Working Paper No 128.

[41] EPA (2016). Health effects support document for perfluorooctanoic acid (PFOA). Document no: EPA822R16003 and Health effects support document for perfluorooctane sulphate (PFOS). Document No: EPA822R16002.

[42] Stein C R *et al.* (2009). Serum levels of perfluorooctanoic acid and perfluorooctane sulfonate and pregnancy outcome. American journal of epidemiology, 170(7), pp.837–846.

[43] The main reason for its prominence is its large sample size. The authors did not consider other studies investigating this endpoint to be sufficiently powered.

[44] Hopkins *et al.* (2018). Recently Detected Drinking Water Contaminants: GenX and Other Per- and Polyfluoroalkyl Ether Acids. American Water Works Association Journal 110:7 p.13–28.

[45] IARC (2018). Perfluorooctanoic acid (PFOA).

3.1.2 Responses to levels of exposure

In the absence of data showing clear dose-response relationships, this study has instead considered health impacts found by epidemiological studies of populations at three levels of exposure: *(1) background (low) PFAS exposure levels; (2) elevated (medium) PFAS exposure levels and (3) occupational (high) exposure.*

Individuals with a higher level of exposure to PFAS can be expected to have a higher concentration of the contaminant in their blood, resulting in elevated health risks. The Expert Health Panel from Australia noted that individuals in highly exposed communities typically have a blood serum concentration about ten times higher than the general population while workers can have a blood serum concentration one thousand times higher than the general population.[46] In other words, it is assumed that the blood serum concentration serves as a rough proxy of PFAS exposure.

Blood samples from population studies such as the National Health and Nutrition Examination Survey (NHANES) in the United States were assumed to provide information on background (low) PFAS exposure. Medium and high PFAS exposure levels were drawn from epidemiological studies based on populations affected by known incidents of PFAS contamination. Communities in close proximity to PFAS production or with PFAS-contaminated drinking water were considered to have been exposed at medium levels while occupationally exposed individuals, e.g., at chemical production plants, were considered to have high levels of exposure.

Some adverse health impacts appear to materialise at high PFAS exposure levels while for other conditions background exposure generates an elevated risk of disease. Carcinogenicity is most clearly linked with a high level of exposure to PFAS. One study[47] found the risk of kidney cancer among residents in close proximity to PFAS contamination was elevated only among those with an above-average level of exposure. Factors that may lead some residents in the same community to have a higher level of exposure than others include the person's age, the number of years lived in the community, and the level of contamination in his or her household's drinking water. The IARC (2018) assessment also concludes that the evidence regarding the elevated risk of kidney cancer is most convincing for the case of occupational exposure, the highest category of exposure.[48]

At the same time, it is not possible to rule out that other residents in the same community with a below-average exposure to PFAS do not have an elevated risk of kidney cancer. The lack of statistical significance may be due to the low risk of kidney cancer in the general population.[49]

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[46] Australia Government Department of Health (2018). Expert Health Panel for Per- and Poly-Fluoroalkyl Substances (PFAS).

[47] Vieira V M *et al.* (2013). Perfluorooctanoic acid exposure and cancer outcomes in a contaminated community: a geographic analysis. Environmental health perspectives, 121(3).

[48] IARC (2018). Perfluorooctanoic acid (PFOA).

[49] National Cancer Institute [NCI] Surveillance, Epidemiology, and End Results data for 2005–2011. The kidney cancer endpoint is also difficult to assess as the survival rate is high at 73%. Testicular cancer, which is another possible endpoint of PFAS exposure, has an even higher survival rate of 95%. Studies with a large sample over a long time frame have a greater likelihood of detecting a differential risk of developing these types of cancer.

Metabolic disease is linked with all levels of PFAS exposure with less severe endpoints such as elevated cholesterol and ulceritis associated with background (low) exposure and more critical endpoints such as liver damage associated with elevated (medium) exposure. The link between the level of PFAS exposure and health endpoints appears to be similar for endocrine disruption and developmental toxicity. Studies suggest that background (low) levels of PFAS contamination can lead to immunotoxicity, especially for infants and children.

3.1.3 Quantifying impacts

A quantitative valuation or monetisation was then undertaken for a selection of the identified health endpoints for which there is a reasonable level of global consensus. Given the limited epidemiological evidence from the specific contexts, the assessment considers "what-if" scenarios. These scenarios assume the transferability of quantitative findings from epidemiological studies from one context to another in some cases, and the subsequent impacts.

The quantitative findings from epidemiological studies are typically in the form of a standardised mortality ratio, an odds-ratio or a relative risk. These statistical terms reflect the elevated risk in an "exposed" population compared with a "less exposed" population after controlling for other factors.[50] The assessment selected risks that were estimated with a high level of confidence. In statistical terms, this implies that the risk was estimated with a margin of error of 5% or less.

The what-if scenarios constructed define linkages between PFAS exposure, the health endpoint and mortality related to the endpoint. Additional studies that investigated the relationship between the health endpoint in question and mortality were also reviewed to characterise the last linkage in the chain of the what-if scenario. The estimated number of health impacts such as deaths through the what-if scenario was then monetised using the "value-of-statistical-life" approach.

The quantitative analysis applies the lower bound of the range recommended by ECHA of EUR 3.5 to EUR 5 million per life lost.[51] The ECHA value of life estimates are commonly used by regulatory agencies in Europe. The lower bound value is also comparable to the value of a statistical life in the EU reported by the OECD, which was EUR 3 million in 2012.[52] When adjusted for inflation, the OECD value approaches the minimum ECHA value.

The monetised figures presented in this study should be understood as the minimum health-related costs of inaction in that only a few health endpoints and a few impacts of these endpoints could be investigated. More data on exposure-response relationships is

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[50] Epidemiological models may control for a wide range of individual and environmental factors such as age, gender, educational background and occupation.

[51] ECHA (2016). Valuing selected health impacts of chemicals: Summary of the results and a critical review of the ECHA study.

[52] OECD (2012). Mortality risk valuation in environment, health and transport policies.

needed for estimating the impacts with respect to other endpoints. The monetised figures can provide an indication of the potential costs of inaction, and where more research is needed to develop more robust what-if scenarios and estimations.

3.1.4 Aggregation

Estimates of impacts or costs were then aggregated across the Nordic countries and the EEA when possible. A major challenge in carrying out the aggregations was the determination of the size of the relevant exposed population. For example, the scenarios for occupational (high) and elevated (medium) levels of exposure required assumptions regarding the number of chemical plants or other sources of PFAS contamination and the average number of persons exposed in each location.

To the extent possible, information to use as a basis for these assumptions were gathered through the case studies. A range of plausible values was considered in the absence of conclusive information. The scenarios for background (low) exposure assume that all individuals living in the Nordic countries or the EEA are affected. The estimations for background (low) exposure could then draw on country-level population statistics available from Eurostat.

The annual number of deaths or cases of a health conditions were generated for the exposed population based on the level of exposure and the epidemiological evidence. The additional level of mortality and disease can therefore be understood as the annual costs due to PFAS exposure for the relevant geographic area – the Nordic countries or the EEA – under the specific scenario. These costs would not be incurred if the PFAS exposure, as defined by the scenario, did not occur. Therefore these estimated costs can be understood as potential costs of inaction.

The analysis generated a point estimate, a lower bound and an upper bound for each scenario. The generation of these three different values stem from the findings of the epidemiological studies, which provided the parameter relating to the level of exposure to PFAS and the elevated health risk. The point estimate was calculated using the main finding from the epidemiological study. The 95% confidence interval for the finding from the epidemiological study was used to generate the lower and upper bound estimates.

The findings from the estimations can be found in Section 5.1. The calculations underlying these estimations including the parameter values can be found in Annex 2.

3.2 Environment-related costs

Two distinct types of environment-related cost are associated with the present research:

- environmental remediation; and
- loss of ecosystem services.

3.2.1 Approaches to environmental remediation

The most technically and economically efficient techniques for reducing contamination of the environment with PFAS arise at manufacture and application prior to sale to end-users, and are as follows:

- using alternatives;
- improved containment at industrial sites manufacturing PFAS;
- increased use efficiency of PFAS materials, for example by re-cycling unused solution at manufacturing sites. Recycling of most applications post-consumer is generally not feasible. A possible exception may be AFFFs that have gone past their use-by date; and
- improved containment at industrial sites using PFAS, for example using controlled application processes and controlled disposal of residues.

Using these techniques, PFAS will either not be present at all, in cases where non-PFAS alternatives are used[53], or where they are used, the volume of material requiring treatment will be limited. However, these measures address only part of the problem: except for the use of alternatives, they are all associated with some level of discharge and they cannot influence contamination associated with goods used outside manufacturing or processing sites. In some cases, AFFFs being a notable example, dispersion to the environment is immediate and total, upon use.

Costing the first set of options set out above is beyond the scope of this report. Costs of improving containment and use efficiency[54] will be internalised by producers and business consumers. In many cases any improvement and associated costs will reflect legislative demands and the permit conditions that facilities are required to operate to. There will be some cost to government, for example through the use of PFAS alternatives at military airbases. Analysis of these costs would require a counterfactual scenario to be developed where alternatives to PFAS were defined, along with differences in likely permit conditions, extending the current assessment to a full cost-benefit analysis.

Environmental remediation may deal with:

- contaminated soils
- contaminated groundwater
- contaminated surface water
- targeted collection of goods containing PFAS at end-of-life to reduce the volume of material that needs to be treated.

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[53] Some "alternatives" are not impact-free. The BREF document on the tanning of hides and skins notes a trend to using shorter chain (C4 or C6, rather than C8 perfluoro compounds). The shorter chain fluorocarbon resins are described (as of 2013) as being more favourably assessed toxicologically but are as persistent in the environment as the longer chain PFAS.

[54] Increased use efficiency will lead to at least some payback through reduced demand for new material.

Targeted collection of goods containing PFAS at end-of-life is not a viable option in most cases. Some applications, such as the use of aqueous film-forming foams (AFFFs) lead to direct contamination of the environment. The range of other applications has become so extensive that separation of goods, for example at waste processing sites, would be impractical, as is evident from the problems faced across Europe with respect to the efficient recycling of another widely dispersed material, plastic. Even if it were practicable to some extent, the option would still leave some level of contamination present as collection processes would never capture all contaminated material and emissions will arise during the use phase.

Environmental remediation of PFAS contamination is not straightforward. Concawe[55], an environmental research and advisory body for the oil industry, notes that many remediation techniques used for other contaminants are ineffective for PFAS because of their low volatility (preventing the use of gas stripping) and their resistance to biological degradation. With this in mind, the main techniques for removing PFAS from the environment involve:

- removal of soils; and
- groundwater extraction and PFAS adsorption onto activated carbon or resins.

Soil removal is a reasonably straightforward process, though it can clearly create a large quantity of soil that needs either further treatment or storage. Storage of PFAS at authorised landfills may lead to leaching into surrounding areas because standard leachate treatment plants are not able to effectively treat these substances.[56] The use of landfill would also place a burden on space at landfills, particularly if contaminated material is required to be stored at the limited number of sites that are licensed to deal with hazardous wastes.

One alternative to storage at landfill is to destroy PFAS through incineration, though this itself is not straightforward (or inexpensive) as it requires use of very high temperatures. Complete destruction of PFOS requires a temperature of 1,000 to 1,200 °C.[57] Associated costs are high because of the significant energy inputs that are required and the likelihood that soil (etc.) volumes will be large. Modern municipal and hazardous waste incinerators can reach high temperatures, e.g. 800 °C or more, and at such temperatures the PFAS on a treated consumer product may break down. The use of lower temperatures can lead to the generation of hazardous by-products.[58]

The Concawe report also discusses stabilisation of PFAS within soils using additives such as activated carbon, and solidification of soils using concrete mixes. Both have been shown to greatly reduce the potential for leaching. However, neither approach provides

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[55] Concawe (2016). Environmental fate and effects of poly- and perfluoroalkyl substances (PFAS). Report no: 8/16.

[56] Oliaei F *et al.* (2013). PFOS and PFC releases and associated pollution from a production plant in Minnesota (USA). Environmental Science Pollution Research. 20: 1977–1992.

[57] Schultz M *et al.* (2003). Fluorinated alkyl surfactants. Environmental Engineering Science 20(5) 487–501. Yamada T *et al.* (2005). Thermal degradation of fluorotelomer treated articles and related materials. Chemosphere 61, 974–984.

[58] Yamada T and PH Taylor (2003). Final Report: Laboratory scale thermal degradation of perfluorooctanyl sulfonate and related precursors. Final Report for 3 M Company.

a permanent solution to the problem of PFAS contamination. These approaches could be seen as creating a potentially large number of hazwaste landfills across Europe.

A further option is soil washing, moving PFAS to the aqueous phase where it can be filtered and retrieved. Concawe reports trials showing a reduction in concentrations *below target levels* after two washing cycles.[59] No information was available on the quantities of sludge or filtrate generated, materials that would need further storage or treatment. Concentrating the PFAS up would have the benefit of reducing the quantity of contaminated material, which would in turn reduce demand for storage or incineration.

The most commonly applied treatment for contaminated groundwater is extraction and use of granular activated carbon (GAC). The efficiency of extraction of PFOS is in the order of 90%, though efficiency for other PFAS (e.g. PFOA) can be much lower especially for short-chained PFAS like PFBA. The characteristics of the absorptive medium can be adapted to specific PFAS, though this leads to trade-offs with improved recovery of some species and lower recovery of others. Spent recovery media are typically incinerated at high temperature.

Other effective treatments are reverse osmosis which is commonly used for preparation of drinking water[60], ion exchange and nano-filtration. All cases will generate wastes that require either specialised storage or high temperature incineration.

Concawe reports on a number of other innovative methods currently being explored, such as photolysis/ photocatalysis, reductive decomposition, advanced oxidation and sonolysis. However, none seem close to application. In particular, these technologies are unlikely to be feasible for high flowrate, low concentration applications, precisely the conditions faced for environmental remediation.

The potential for contamination of surface waters may also need to be considered. In many cases, contamination would be better treated at source (i.e. at the factory or at a site of soil contamination) than downstream where concentrations will be more dilute. Information from the Veneto Region below provides a case where contamination may be from diffuse sources across the Region. A first response should be to ensure that the emitting industries either treat their own waste water or discharge to sewer for treatment at a waste water treatment plant (WWTP) if this does not already happen. This may further require upgrading of the WWTP and where contamination of surface waters persists, further remedial action may be necessary.

In summary, a number of techniques are available for PFAS remediation, but they are not straightforward and as such are likely to be costly. The information above has been used to check the validity of options adopted at various locations in the case study material presented below.

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[59] The report does not state what these target values were. Other parts of the report discuss a range of 0.1 to 0.5 µg/l, though elsewhere reference is made to 0.023 µg/l.

[60] Tang C Y *et al.* (2007). Effect of Flux (Transmembrane Pressure) and Membrane Properties on Fouling and Rejection of Reverse Osmosis and Nanofiltration Membranes Treating Perfluorooctane Sulfonate Containing Wastewater. Environmental Science and Technology 41: 2008–2014.

3.2.2 *Quantifying the costs of environmental remediation*

Building on the information presented in the previous section, the costs to regulatory and other stakeholders (excluding direct impacts on health and the environment) relate to the following activities:

- survey work to identify sites that are likely not to meet regulatory criteria on PFAS contamination;
- liaison with stakeholders using or living near contaminated resources (public meetings, etc.);
- monitoring concentrations of PFAS before, during and after remediation;
- removal of contaminated soils followed by:
  - storage of these soils at controlled landfill sites, or
  - high temperature incineration, or
  - soil washing to extract PFAS
    - storage or high temperature incineration of contaminated filters, etc.
- extraction of groundwater followed by:
  - use of GAC to absorb PFAS, or
  - use of ion-exchange (IX) resins to absorb PFAS, or
  - reverse osmosis or nanofiltration, which may require expansion of water treatment facilities given the need to generate an additional 15–20% of water for use in the treatment process[61]
    - all of which would need to be followed by storage of collected pollutants or high temperature incineration of contaminated filters, etc.

Stabilisation of PFAS within soils is not considered here to be a long-term solution to the problem for the vast majority of cases, and so is not considered further.

Cost data for the above activities have been taken from the case study examples provided in Chapter 4 and various sources in the grey literature (see Annex 3 for more on this).

Using data from reported cases, analysis can be carried out in two stages:

1. Quantification of the costs of environmental remediation for a standardised situation, e.g.
   a. release of a standardised quantity of PFAS into soil (e.g. 10kg); and
   b. contamination of a drinking water supply
      i. leading to the provision of water from alternative sources for a standardised population (e.g. 100,000 people)

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[61] Black and Veatch (2018) Alternatives Evaluation Report. Emerging contaminants treatments strategies study.

        ii. leading to the requirement for upgrading of water treatment works for a standardised population (e.g. 100,000 people)

2. Extrapolation of the "standardised cases" to national or European level, accounting for:
    a. the number of sites where soils are contaminated by PFAS and where soils will need to be decontaminated or stabilised;
    b. the number of communities served by contaminated water supplies in need of remediation;
    c. the probability that these sites will be remediated; and
    d. the population served by contaminated drinking water supplies.

The analysis that follows identifies a number of uncertainties that affect the analysis, including:

- the quantities of PFAS released;
- the number of contaminated sites;
- the representativeness of case study material; and
- Limited data availability for some activities.

The extrapolation of existing data to new cases is clearly prone to uncertainty. The easiest way of dealing with this would be to define plausible ranges for each variable used in the extrapolation, and to use these to calculate absolute minimum and maximum estimates of cost. Such an approach has three problems:

1. It can provide an extremely broad spread of results.
2. It biases attention to the extremes of the range rather than to the most likely estimate, providing no reason to prefer any value between the two.
3. It typically does not account for possible correlation between input values.

Consideration was given to the use of Monte Carlo analysis to deal with uncertainty. However, it was concluded in the course of the work that this could give a false impression of the quality of the data adopted for analysis. An alternative developed for the presentation of results was to adopt a series of plausible and well-defined scenarios to demonstrate the likely and potential magnitude of damage and reasonable ranges for the results. The assumptions followed for each scenario would be clearly stated with the results in order that readers can understand why and how differences arise.

3.2.3 Quantifying the costs related to loss of ecosystem services

Ecosystem services are typically regarded as falling into four categories:

- supporting services, such as nutrient cycling and soil formation
- provisioning services, such as the production of food, fishing opportunity, raw materials, novel compounds of possible medicinal use and clean water
- regulating services, such as carbon sequestration, water purification, waste cycling, pollination and pest control; and
- cultural services, such as the spiritual and historic significance of natural resources.

Whilst the possibility of PFAS affecting a number of these services is not ruled out, there is a lack of data available for describing associated impact pathways. The most significant omissions concern information on response functions for specific ecosystems and data on stock at risk for specific sites affected by PFAS contamination.

An alternative route, proceeding from emission straight to valuation, is possible using results of studies undertaken to quantify individual willingness to pay (WTP) to avoid the impacts of either PFAS or other substances with PBT or vPvB properties. Two examples have been identified:

1. A study by Sunding (2017) assessing damage to Minnesota's natural resources resulting from 3M's disposal of PFCs in Washington County, Minnesota[62].
2. A UK survey undertaken not on PFAS specifically but for the REACH restriction dossier for D4/D5[63] that considered WTP regarding PBT and vPvB properties.

Sunding's study from the USA covered damage to groundwater, surface water and increased costs of water purification. The groundwater assessment compared the difference in house prices in areas where groundwater was contaminated and used for drinking water, with areas that were uncontaminated. Results showed a decline in house prices of 7.3% in the most affected areas (4.4% in other contaminated communities). The average lost value per home was USD 17,400 or EUR 12,657 (USD 14,000 or EUR 10,184 in other affected communities) with an annualized loss of USD 288 or EUR 209 (USD 231 or EUR 209). Total past and future damage for the period 1971 to 2050 for the 57,000 houses affected was estimated to USD 1.5 billion, or EUR 1.1 billion.

Results were corroborated with surveys of residents and consideration of defensive expenditures via bottled water sales. As part of the assessment WTP to avoid fishing in PFOS contaminated surface waters was estimated from a survey at USD 19 (EUR 14) to USD 45 (EUR 33) per trip depending on the type of fish present ("popular"

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[62] Sunding D L, Damage to Minnesota's natural resources resulting from 3M's disposal of PFCs in Washington County.

[63] RAC/SEAC (2016) Background Document to the Opinion on the Annex XV dossier proposing restrictions on Octamethylcyclotetrasiloxane (D4) and Decamethylcyclopentasiloxane (D5). Committee for Risk Assessment and Committee for Socio-Economic Analysis, European Chemicals Agency, Helsinki.

or “unpopular” species). Total loss to anglers over the period 2008 to 2040 was estimated at USD 121 million (EUR 88 million).

Further to these calculations, restoration costs related to public water supply and point-of-entry treatment units for 2018 to 2050 was valued at USD 396 million (EUR 288 million). It is unclear in the Sunding study what is covered by these restoration costs. Nevertheless, it is presumed that the Sunding study concern the upgrading of water treatment facilities to remove PFAS.

The D4/D5 study using the UK survey, notes the following

> “Quantification of environmental impacts of regulatory policy changes is difficult. In the case of D4/D5 the benefits of the proposed restriction are estimated by considering society’s Willingness to Pay (WTP) for a reduction in potential risks to the aquatic environment. … A representative sample of the UK population (sample size = 829) stated that they were willing to pay €46 per year per person to reduce the risks associated with the PBT substance - D4, and €40 per year per person to reduce the risks associated with the vPvB substance - D5. The WTP for superior quality personal care products (i.e. those that use D4/D5) was estimated at €5 per year per person. This indicates that respondents value the precautionary benefits of reduced potential risk of accumulation of D4/D5 in the aquatic environment at around seven times the value of the loss of beneficial properties provided by D4 and D5 in personal care products.”

The application of the results of the survey recognizes that significant uncertainty exists. Rather than seeking to provide a total estimate of damage to compare against any increase in cost of alternatives, the study compares two alternative WTP estimates. The first WTP estimate is linked to avoidance of environmental harm and the second to the useful properties that are linked to the presence of D4/D5 in personal care products, providing a general indication of societal preference.

These results are discussed further below, though a full quantification by country is not presented. To make such a quantification based on the Sunding analysis of house prices and fishing trips would require additional information that is not available on the scale of the current assessment (e.g. knowledge of angling behavior in areas where there is PFAS contamination). The results of the D4/D5 assessment are based on a relatively small survey, the authors of the work applied them only in a limited way in development of the restriction dossier, not quantifying a total cost but comparing WTP to avoid damage with WTP for the properties that they provide in the end product.

3.2.4 Value transfer

Value transfer, often called benefits transfer in environmental economics, is a practice used to estimate economic values by transferring information available from an already completed study in one context to another, for example by transferring valuation of fishing trips in the USA to a European country.[64] The need for value transfer arises because of the limited amount of valuation data available.

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[64] The methods are described in detail in Navrud S. and Ready R. (eds.) (2007). Environmental Value Transfer: Issues and Methods. Springer.

At its most basic, values are simply transferred from one location to another, with no adjustment. Such an approach is reasonable where the differences between locations are expected to be small. However, in most cases the process is not as simple, where people in one location may respond differently to those in another location for example relating to differences in income, culture, or availability of alternative resources. The validity of the transfer should therefore be evaluated carefully.

Three approaches have been described[65]:

- unit value transfer
- value function transfer; and
- meta-analysis.

Unit value transfer is typically made with adjustment for variation in income:

$$B_{p\prime} = B_S \left(\frac{Y_p}{Y_S}\right)^{ß}$$

Where $B_{p'}$ = adjusted benefit estimate for new location, B_S = original estimate from study site, Y_p and Y_S are the income levels at the new location and study site respectively and ß = elasticity (typically 0.4–1.0). Jacobsen and Hanley[66] found that GDP/capita (i.e. societal income) was a better predictor of WTP than respondents' income, which simplifies the calculations.

International transfer in this context is carried out using exchange rates adjusted for purchasing power parity (PPP). Purchasing power parities are the rates of currency conversion that equalise the purchasing power of different currencies by eliminating the differences in price levels between countries. The production of PPPs is a multilateral exercise involving the National Statistical Institutes of the participating countries, Eurostat and the Organisation for Economic Co-operation and Development (OECD), and is governed by the PPP Regulation.[67] Data are available from OECD.[68]

In our study setting a question that arises is how reliable extrapolation from the USA to Europe might be, given that a significant part of the data identified for this research comes from North America. One response to this question is that there is likely as much or more variation between European countries, as there is between the USA and Europe. Another response concerns the way that the US data are used, often alongside European data and serving to extend the evidence base for the analysis. Consideration has been given to whether there is any clear disparity in US and European estimates.

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[65] Navrud S. (2016). Possibilities and challenges in transfer and generalization of monetary estimates for environmental and health benefits of regulating chemicals. (Presentation at OECD Workshop on socioeconomic impact assessment of chemicals management).

[66] Jacobsen J B and Hanley N (2009). Are There Income Effects on Global Willingness to Pay for Biodiversity Conservation? Environmental and Resource Economics, Volume 43, Issue 2, pp 137–160.

[67] Regulation (EC) No 1445/2007 of the European Parliament and of the Council of 11 December 2007 establishing common rules for the provision of basic information on Purchasing Power Parities and for their calculation and dissemination.

[68] OECD Database: Purchasing power parities. Accessed 10.11.2018.

Value function transfer and meta-analysis add further explanatory variables into the equation to explain how values may vary from site to site. For the present analysis, however, neither technique has proved necessary in a formal sense because of the nature of the data gathered. However, the derivation of ranges and best estimates takes account of some of the principles of value function transfer by recognising non-linearities in costs according to (e.g.) the number of households affected.[69]

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[69] Upon request the excelspread sheets used for the monetarisation and valuation in this report can also be provided along with a guidance on how to use the estimation of costs for value transfer.

4. The case studies

The case studies have multiple roles in this study. One role is to illustrate the impact pathways, i.e., how the production of PFAS and the manufacture of PFAS-containing products, as well as the use and end-of-life disposal of those products, result in emissions to the environment and human exposures. This provides a basis for identifying the impact pathways for similar instances of contamination in other locations.

An additional purpose of the case studies is to gather concrete cost data based on actual instances of PFAS exposure and to translate these into costs per incident. They also help to identify the additional information needed to quantity the negative impacts in a way that will enable them to be extrapolated – if possible – to the Nordic region and then to Europe overall.

The case studies follow the life cycle of PFAS from their production at chemical production facilities, their application in manufacturing of products, the use phase and the impact pathways for wastewater discharges, and then the end-of-life phase and their disposal in landfills. Incineration is not reviewed per se, as the PFAS emissions from this disposal method (air-borne as well as via the bottom ash) are not yet well studied.[70]
Several case studies also provided opportunities for getting human epidemiological data on health effects as well as concrete health-related costs.

4.1 Case Study 1: Exposures due to production of PFAS

Case Study 1 looks at how the production of PFAS results in emissions to the environment, resulting in human and environmental exposure (impact pathways).

4.1.1 Background and context

The production of PFAS can generate extensive emissions. Most PFAS are colorless and odorless[71], and initially they were produced without consideration of the impacts of emissions during their production and processing.

The US company 3M was the first to manufacture a PFAS commercially – the C8, PFOA. It licensed the technology to another US company, Dupont, which developed the polymer Teflon. In the 1970s and 1980s 3M scientists became concerned because laboratory animals exposed to C8s were developing health problems, including birth defects. They alerted Dupont scientists and Dupont started to take measures to protect

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[70] Hansson *et al.* (2016). Sammanställning av befintlig kunskap om föroreningskällor till PFAS-ämnen i svensk miljö. Report Number C 182.

[71] The odor of PFBA has been described as "sharp, similar to butyric acid.

workers exposed in their jobs. Measures to reduce emissions to the environment were not taken until considerably later. Contamination levels at production sites can be high.

A number of lawsuits are underway to prompt action from manufacturers to clean-up contamination. The level of damages and settlements reached depend on a number of factors which include the identified harm to the environment and human health. Some settlements include punitive damages and funds to support the clean-up of the contaminated water.

In February 2018, a settlement of USD 850 million (EUR 618 million) was reached between 3M and the state of Minnesota.[72] The funds are expected to support the development of alternative water supplies, treat existing water supplies, finance water conservation and efficiency projects and support groundwater recharge projects.[73] While it is the largest settlement to date in the United States for a case of PFAS contamination, the amount originally sought by the plaintiff was USD 5 billion.[74] The settlement amount diminishes in comparison to the company's market value (about 1%) and the profits made on the PFAS-containing products.[75] 3M is facing other legal actions: a February 2018 news article reported that 37 cases related to PFC contamination against 3M are underway.[76]

4.1.2 Cases of contamination

Chemours factory complex in Dordrecht, Netherlands

The Chemours plant in the Netherlands belonged to the company Dupont until 2015, when Dupont spun off its specialty chemicals division, which included production of fluorochemicals such as the fluoropolymer Teflon. The Dordrecht plant is Chemours' biggest production site in Europe, employing over 550 employees.[77] In addition, Chemours has a total of 35 production sites worldwide, 25 in North America, four in Europe, Africa and Middle East, four in Asia and two in South America.

In 2012 Dupont had replaced production of C8 with GenX, a perfluoroalkyl ether carboxylate alternative that includes FRD-902, FRD-903 and E1. While GenX seems to be less bioaccumulative than PFOA[78], reports filed by Dupont with the USEPA indicated that the replacement chemical may cause some of the same health problems as PFOA.[79]

Although the Dordrecht facility supposedly stopped PFOA production in 2012, toxicological studies found concentrations of PFOA in grass surrounding the plant that

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[72] Kary T, 3M Settles Minnesota Lawsuit for $850 million. Bloomberg, 20.02.2018. Accessed 08.13.2018.

[73] Marten Law (website). The True Cost of Scotchgard: 3M to Pay Minnesota $850 Million in Perfluorochemical Settlement. Accessed 10.10.2018.

[74] Marcotty J, State alleges 3M chemicals caused cancer and infertility, alleges $5 billion in damage. Star Tribune, 21.11.2017. Accessed 10.10.2018.

[75] Alder C, 3M settles Minnesota groundwater lawsuit for $850 million. 21.02.2018. Accessed 09.09.2018.

[76] Marcotty J, 3M settles groundwater lawsuit for $850 million, Star Tribune, 20.02.2018. Accessed 15.10.2018.

[77] Scott A, Dutch Chemical Plant Under Investigation, Chemical and Engineering News, 18.04.2016. Accessed 10.11.2018.

[78] Beekman M *et al.* (2016). Evaluation of substances used in the GenX technology by Chemours, Dordrecht, RIVM Letter. Report 2016-0174.

[79] Lerner S (2016). New Teflon Toxin Causes Cancer in Lab Animals, The Intercept, 03.06.2016. Accessed 18.09.2018.

were inconsistent with that claim.[80] Today the facility discharges both FRD-902 and FRD-903 into wastewater, which is pre-treated before being discharged into sewage treatment. FRD-903 is also released into the air via the factory's chimneys.[81]

In 2016, the Dutch government asked the Dutch National Institute for Public Health and the Environment (RIVM) to evaluate the existing knowledge of the toxicity and health effects of PFOA (C8), which had been released from the Chemours facility from 1970 until 2012.[82] RIVM estimated that 750,000 people were exposed to high levels of PFOA due to their residence in cities close to the Dordrecht plant and the Merwede river downstream.[83] RIVM also detected PFAS and GenX in vegetable gardens within 1 kilometer of the Dordrecht plants, suggesting pathways into humans.[84] While levels of contamination do not exceed advisory thresholds, residents also face exposure from the air directly as well as drinking water. Thus, residents are advised to consume produce from their vegetable gardens in moderation.

The Chemours facility used PFOA to produce the fluoropolymer known as Teflon, a production process similar to that carried out at a Chemours (formerly Dupont) plant in West Virginia.[85] The West Virginia plant has been the target of legal action since 2001, when residents brought a class action against Dupont concerning their exposure to PFOA. Under a 2004 settlement, Dupont agreed to fund a medical monitoring program for 70,000 persons as well as new water treatment systems. After ten years, the C8 panel of scientists following the medical monitoring program concluded that six illnesses were probably linked to the exposure to PFOA: kidney and testicular cancer, ulcerative colitis, thyroid disease, pregnancy-induced hypertension and high cholesterol. More than 3,500 personal injury claims were pending against Dupont and Chemours when agreement was reached to settle the claims for USD 671 million (EUR 488 million).

The Netherlands government requested a medical monitoring study of the health effects resulting from the exposure in Dordrecht, following the approach taken with the Dupont case in West Virginia. The study undertaken by RIVM found the levels of PFOA in Dordrecht's drinking water to have been lower than in the US case. However, concentrations in the atmosphere between 1970 and 2012 had exceeded the legal amount. RIVM's risk assessment concluded that under the most unfavourable scenario for concentration levels, some residents might experience impacts on the liver. However, risks of cancer and to the unborn child were considered to be limited.[86]

Chemours was required to reduce GenX emissions from 6,400 kg/year to 2,000 kg/year. In September 2018, the company announced it would invest EUR 75 million in

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[80] No Author, Another Chapter: Chemours releases GenX and PFOAs into waters globally, Encore, 08.08.2018. Accessed 10.10.2018.

[81] RIVM (2016). GenX (Website in Dutch).

[82] RIVM (2016). Risicoschatting emissie PFOA voor omwonenden (In Dutch).

[83] No Author (2018). Another Chapter: Chemours releases GenX and PFOAs into waters globally, Encore, 08.08.2018. Accessed 10.10.2018.

[84] RIVM (2018). Risicobeoordeling van GenX en PFOA in moestuingewassen in Dordrecht, Papendrecht en Sliedrecht. (In Dutch with English Summary).

[85] Nair A S, DuPont settles lawsuits over leak of chemical used to make Teflon. Reuters Business News, 13.02.2017. Accessed 10.09.2018.

[86] RIVM (2018). Risicobeoordeling van GenX en PFOA in moestuingewassen in Dordrecht, Papendrecht en Sliedrecht. (In Dutch with English Summary).

reducing emissions of GenX and organic fluorinated substances, by installing active carbon filters and other technical solutions which are expected to eventually remove up to 99% of the targeted substances.[87]

Note that a Chemours (formerly Dupont) facility in Fayetteville, North Carolina is also the target of legal action for polluting a wide geographical area. The plant discharged large amounts of GenX into the Cape Fear River, the major source of drinking water for downstream cities, including Wilmington (110,000 pop.). A lawsuit filed against Dupont and Chemours in February 2018 consolidated three class action suits and is seeking funds for environmental cleanup (cost of water filtration), monitoring, and punitive damages for illness and reduced property values.[88] In November 2018, state authorities and Chemours announced they had reached an agreement which will cost the company USD 12 million (EUR 8.7 million) in civil penalties, in addition to USD 1 million (EUR 727,400) in investigation costs. Furthermore, if the agreement is approved by the court in its current state, Chemours has committed to reduce its emissions significantly. If reduction targets are not achieved additional fines will be paid.[89]

Veneto region, Italy

A large-scale contamination of PFAS was discovered in the Veneto Region of Italy in 2013, directly affecting groundwater, surface water, drinking water and land in an area of over 200 square kilometers.[90] The contamination was attributed to emissions from a facility operated by the company Miteni since 1964. The chemical company produced several PFAS-containing products such as herbicides and pharmaceuticals. The company reported on their website that production of PFOS and PFOA stopped in 2011[91], but their product catalog still includes PFHxS and PHxSF.[92]

The Veneto Region's response to the incident drew on a wide range of stakeholders across sectors. Several monitoring studies were undertaken to gather information on the levels of contamination and their impacts. Because of this contamination, standards were introduced for water, agriculture and food. In April 2018, a legal case was brought against Miteni[93] by the Public Prosecutor's Office in Vicenza.[94]

The contamination included a number of PFAS compounds. Monitoring data collected between 2013 and 2015 identified the following specific compounds: perfluorobutanoic acid (PFBA), perfluorobutane sulfonate (PFBS), perfluorodecanoic

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[87] Chemours, The Chemours Company Takes Significant Action to Minimize Emissions. Accessed 08.09.2018.

[88] Reisch M S, Merged lawsuit filed against DuPont and Chemours in North Carolina, Chemical and Engineering News, 05.02.2018, Accessed 08.09.2018.

[89] Wagner A, Chemours to pay $12 Million fine as part of GenX Agreement, StarNews Online, 21.11.2018. Accessed 01.12.2018.

[90] WHO Europe (2016). Keeping our water clean: The case of water contamination in the Veneto Region, Italy.

[91] As claimed by Miteni Company on their website, available here.

[92] This information was obtained by an NGO (IPEN and Alaska Community Action on Toxics (ACAT)) submission of information specified in Annex E of the Stockholm Convention pursuant to Article 8 of the Convention, and confirmed with a product research on the company's website using CAS numbers for PFHxS and PFHxSF.

[93] In October 2018, the company filed bankruptcy.

[94] No author, La procura di Vicenza indaga sulle sostanze cancerogene nell'acqua, Le Iene, 21.05. 2018, Accessed October 2018 (in Italian).

acid (PFDA), perfluorododecanoic acid (PFDoDA), perfluoroheptanoic acid (PFHpA), perfluorohexanoic acid (PFHxA), perfluorohexane sulfonate (PFHxS), perfluorononanoic acid (PFNA), perfluoropentanoic acid (PFPeA) and perfluoroundecanoic acid (PFUnDA).[95] Another source indicated that PFPeA, PFHxA, PFHpA, PFHxS, PFNA, PFDA, PFUnDA, PFDoDA, PFBA, and PFBS were present in the contaminated waters.[96]

Residents in the surrounding areas were exposed to the contamination for decades. The highest combined concentration levels of PFAS (estimated to be 1214 ng/l) were found in the municipalities of Brendola, Lonigo and Sarego[97] among others.[98] Estimates for the number of affected individuals vary from 120,000[99] to 350,000 people.[100]

The Veneto Region Environmental Agency carried out studies identifying two main pathways for the contamination in the area. One pathway was through contaminated wastewater emitted from the chemical factory directly into a creek and the surrounding groundwater. The second pathway was from the wastewater plant to a canal that drained into the surface waters of the Brenta river.[101, 102] This river basin, which is characterised by a 100–200 metre deep bed of pebbles and gravel, is highly permeable, increasing the spread of the contamination.

The contaminated water was drunk by residents in the area and also made its way into the food chain via contaminated water used for irrigation. Contamination was found in foods such as eggs and fish. Agriculture in the Veneto Region represents about 10% of national production suggesting a high risk for contaminated foods being shipped and consumed in other parts of the country or even in other countries.[103]

Information on health risks was collected through a biomonitoring study undertaken between July 2015 and April 2016 for different population groups including people working in the agricultural sector and people residing in uncontaminated areas, which served as a control group. Agricultural workers were given greater attention due to their greater risk of exposure to crops and livestock. An analysis found a higher risk of mortality, diabetes, cerebrovascular diseases, myocardial infarction and Alzheimer's disease. Females had an increased morbidity for several conditions. The results are summarized in Table 8.

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[95] Mastrantonio M *et al.* (2017). Drinking water contamination from perfluoroalkyl substances (PFAS): an ecological mortality study in the Veneto Region, Italy. The European Journal of Public Health. Feb 1;28(1):180–185.

[96] ISS (National Institute of Health). Dept of Environmental Health (no date). Perfluorooctanoic acid (PFOA) pollution of groundwater: the case study of Veneto, Italy.

[97] Ibid.

[98] Regione di Veneto (2018). Piano di Sorveglianza Sanitaria Sulla Popolazione Esposte alle Sostanze Perfluoroalchiliche (in Italian), Rapport no 04, p.10.

[99] WHO Europe (2016). Keeping our water clean: The case of water contamination in the Veneto Region, Italy.

[100] No author, Another Chapter: Chemours releases GenX and PFOAs into waters globally, Encore, 08.08.2018. Accessed 10.10.2018.

[101] WHO Europe (2016). Keeping our water clean: The case of water contamination in the Veneto Region, Italy.

[102] ISS (National Institute of Health). Dept of Environmental Health (no date). Perfluorooctanoic acid (PFOA) pollution of groundwater: the case study of Veneto, Italy.

[103] No author (2018). La procura di Vicenza indaga sulle sostanze cancerogene nell'acqua, Le Iene, 21.05. 2018, Accessed October 2018 (in Italian).

Table 8: Disease risk ratios – Veneto region

	Males		Females	
	Number of deaths	Relative risk (95% confidence interval)	Number of deaths	Relative risk (95% confidence interval)
General mortality	21,149	1.19 (1.17–1.21)	20,692	1.21 (1.19–1.23)
Diabetes	292	1.21 (1.06–1.38)	595	1.48 (1.34–1.62)
Cerebrovascular disease	1,871	1.34 1.27–1.41)	2,271	1.29 (1.23–1.34)
Myocardial infarction	1,900	1.22 (1.16–1.28)	1,458	1.24 (1.17–1.32)
Alzheimer's disease	89	1.33 (1.05–1.70)	178	1.35 (1.09–1.67)
Kidney cancer		1.07 (0.90–1.28)		1.32
Breast cancer		n.a.		1.11
Parkinson's disease				1.35

Source: Mastrantonio M *et al.* (2017). Drinking water contamination from perfluoroalkyl substances (PFAS): an ecological mortality study in the Veneto Region, Italy. The European Journal of Public Health. Feb 1;28(1):180–185.

Monitoring studies also found a higher rate of mortality and disease (liver, bladder and kidney cancer and cirrhosis) among employees at the chemical plant.[104]

Within three months of the 2013 announcement of PFAS contamination in the Veneto Region, authorities installed activated carbon filters in drinking water treatment plants. The estimated cost of the installation was EUR 2 million, which was paid for by the Veneto Region's government and taxpayers. Activities related to the Health Surveillance Plan cost an additional EUR 4.3 million. These modifications resulted in a substantial decline in the concentration of PFOA in water from about 1475 ng/l to 386 ng/l, and a decline in PFOS from 117 ng/l to 36 ng/l.

Maintaining the carbon filters will also incur costs. One source estimated the cost of a changed set of filters at EUR 150,000 while chemical monitoring costs EUR 750,000, leading to a total cost of the filter installation of EUR 900,000 per year.

The short-term cost (5 years) was estimated to be EUR 6.5 million while investment in the medium-term to improve water treatment plants was estimated to be EUR 4.2 million. An alternative solution to invest in new water pipelines was estimated to be EUR 61.7 million. Table 9 translates the cost findings to the production cost of drinking water.

Table 9: Production cost of drinking water

	2014 (EUR cent/m3)	2015 (EUR cent/m3)
Cost without PFAS pollution	4.7–8.3	4.0–8.5
Cost with PFAS pollution	10.0–18.7	6.6–21.0

Source: ISS (National Institute of Health). Dept of Environmental Health (no date). Perfluorooctanoic acid (PFOA) pollution of groundwater: the case study of Veneto, Italy.

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[104] WHO Europe (2016). Keeping our water clean: The case of water contamination in the Veneto Region, Italy.

Between 2013 and 2014, the chemicals company also installed activated carbon filters for wastewater treatment.[105]

Fluorochemical production sites – data limitations and assumptions

As the case studies indicate, fluorochemical production plants have historically been major sources of PFAS exposure. One of the challenges of this study was to estimate the current number of fluorochemical production sites in the Nordic countries and in Europe. The constant changes within the fluorochemicals/fluoropolymers industry made it difficult to use data sources from the past that identified sites by company. For example, Elf Atochem had merged with Total/Fina to become Alofina which later became, Arkema. Similarly, ICI Fluorochemicals was sold to INEOS, which in turn sold that part of its business to Mexichem.

In addition, production is shifting from Europe and North America to Asia, particularly China, and other regions. Among the major producers are companies such as Daikin, Asahi Glass, Honeywell, Mitsui Chemicals, Gujaratfluorochemicals, and Dongyue Chemicals. BASF, Solvay, and Dupont are also global players.

The US-based FluoroCouncil represents a number of PFAS producers internationally. Members include Archroma, Arkema France, AGC Inc., Chemours, Daikin Industries, and Solvay Specialty Polymers. Dynax Corporation and Tyco Fire Products are associate members.

Regulatory pressure has also contributed to changes in the industry. Production of the long-chain PFOA and PFOS was phased out years ago by companies like 3M, Dow-Dupont, and BASF, which for the most part switched to production of short-chain PFAS. However, company websites seldom provide information on which fluorochemicals are produced and at which sites.

The list presented in Table 10 is the result of the search efforts carried out for this study. It assumes that production of fluorochemicals and/or fluoropolymers is taking place in 2018 at the following sites within Europe:

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[105] ISS (National Institute of Health). Dept of Environmental Health (no date). Perfluorooctanoic acid (PFOA) pollution of groundwater: the case study of Veneto, Italy.

Table 10: List of manufacturers of fluorochemicals and/or fluoropolymers

Country	Company and site of plant	What is being produced
Belgium	3M (Zwijndorf)	Fluorochemicals
France	Arkema (Pierre-Bénite)	Fluoropolymers (PVDF)
	Solvay Solexis (Tavaux)	Fluoropolymers (PVDF)
	Daikin Chemical France S.A.S.[1]	Fluorochemicals
Germany	Dyneon (Gendorf)	Fluorochemicals, fluoropolymers (PTFE, FEP, PFA, THV)
	BASF (Ludwigshafen)	n.a.
Italy	Solvay Solexis (Spinetta-Argeno	Fluoropolymers) – PTFE, MFA
	Heroflon S.p.A. (Collebeato)	Fluoropolymers (PTFE compounds and micropowders)
	Miteni (Trissino) [2]	Fluorinated intermediates; performance fluorinated products
Netherlands	Chemours (Dordrecht)	Fluoropolymers (PTFE, FEP)
	Daikin Chemical Netherlands (Oss) – Pre-compounding of fluoroelastomers	Fluorochemicals
United Kingdom	AGC (Blackpool)	Fluoropolymers – PTFE, PFA

Source: 1) Daikin Europe, manufacturing of fluoroelastomer base polymer and polymer processing aids.

2) Miteni files bankcruptcy in October 2018.

Based on this list, it is further assumed that the number of PFAS production sites in Europe is between 12 and 20 plants. However, in this study the authors have not been able to identify any PFAS production facilities in the Nordic countries.

4.2 Case Study 2: Exposures due to manufacture and commercial use of PFAS-containing products

4.2.1 *Background and context*

The many facilities where PFAS are used in the manufacture of consumer goods and other products also constitute major sources of PFAS emissions to the environment. A 3M study from 2000 estimated that 15% of all indirect emissions of POSF (perfluorooctane sulfonyl fluoride, compound that is used for producing PFOS) occurred during manufacturing from secondary applications.[106] In addition, the use of PFAS as surfactants and coatings in providing commercial services, such as professional cleaning, has also been linked to hotspot contamination.

A mapping of PFAS pathways in Sweden concluded that quantifying the emissions released from the many uses of PFAS in products might not be possible due to lack of data and the "diffuse character" of certain areas of usage.[107] To increase information on how and where PFAS are used, the Swedish Chemicals Agency has recently introduced

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[106] Alexandre G. Paul *et al.* (2008). A First Global Production, Emission, And Environmental Inventory For Perfluorooctane Sulfonate. Environmental Science & Technology 2009 43 (2), 386–392.

[107] Hansson *et al.* (2016). Sammanställning av befintlig kunskap om föroreningskällor till PFAS-ämnen i svensk miljö. Report Number C 182.

a requirement for companies to report all products containing added PFAS compounds and their use to the Swedish "Products Register"[108], starting from 1 January 2019.

This case study identifies several industrial activities that have the potential to release PFAS to the environment, either directly or indirectly, e.g., through discharges to wastewater treatment works on site or off-site via sewerage systems. It provides brief descriptions of cases where contamination has been identified, leading to costs for remediation.

4.2.2 Cases of contamination

Textile and leather manufacturing

The textile industry is one of the most extensive users of PFAS. The water repellency and stain resistance qualities of PFAS have led to widespread PFAS treatment of items intended for use outdoors such as raincoats, snowsuits for children, ski jackets, shoes and umbrellas as well as outdoor equipment such as tents, awnings and sails. Other items frequently treated with PFAS include carpets, upholstery, and leather products. Textile applications can account for an estimated 35% of the demand for fluorotelomers. This demand is projected to grow by 14% by 2020.[109]

Awareness within the textile industry concerning the health and ennvironmental impacts of PFAS is growing and alternative non-florinated methods of treating fabrics and leather for water repellency have been analysed.

Though the case study of PFAS contamination in the Veneto region above focused on the facility producing fluorochemicals operated by Miteni, sources of the contamination may also include hundreds of smaller textile and leather companies. In fact, the Veneto Region is known for its model of "industrial clusters" where multiple companies producing the same good are located in the same area.

As shown in Figure 3 below, several industrial clusters producing goods that could contain PFAS were present in the contaminated area.

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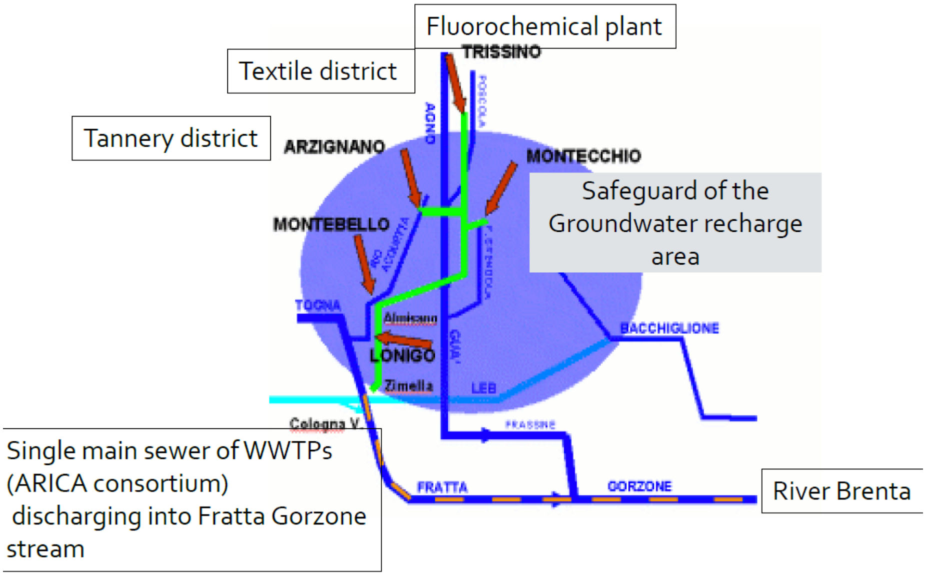
[108] Swedish Chemicals Agency (2018). (News) The Swedish Chemicals Agency is introducing a requirement to report PFAS to the Products Register. Accessed September 2018.

[109] Press release (No date) Fluorotelomers Market to Reach USD 539.3 Million Worldwide by 2020, Digital Journal. Accessed 10.11.2018.

Figure 3: Industrial clusters that could contribute to PFAS contamination pathways



Source: ISS (National Institute of Health). Dept of Environmental Health (no date). Perfluorooctanoic acid (PFOA) pollution of groundwater: the case study of Veneto, Italy.

Miteni's website[110] includes a statement from April 2016 expressing the opinion that the large area contaminated by PFAS

> "must necessarily refer to the system of consortium discharges to which hundreds of local companies are connected. Miteni has not been producing PFOS and PFOA since 2011, and before, the wastewater from the facility was sent to external treatment systems. PFOS and PFOA are still used today by over two hundred industries in the tanning and manufacturing industries in the area that buy them on the foreign market, companies that are connected to the same consortium discharges to which Miteni is connected."

The proportion of textile and leather manufacturers in Europe using PFAS to treat their products is not known, but even a small percentage such as 3% could be significant. Statistics from Eurostat[111] indicate 262 textile manufacturers in the EEA with more than 250 employees in 2015, and another 61,685 textile manufacturers with less than 250 employees, i.e., SMEs.The country with the highest number of textile manufacturers is Italy (13,930 textile manufacturers). Manufacturers of leather and leather goods in 2015 included 159 companies with more than 250 employees, and another 37,120 companies with less than 250 employees.

Case Study 4 below looks at carpets, a textile-related consumer product, while Case Study 5 includes a description of historic pollution in the State of Michigan involving a former leather tannery.

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[110] Miteni Company Website.

[111] Eurostat Annual enterprise statistics by size class for special aggregates of activities (NACE Rev. 2) [sbs_sc_sca_r2].

Metal plating, including chromium plating

The use of PFOSs as a wetting agent/fume suppressant in chromium plating was first reported in 1954[112], and additional types of PFAS have been developed for such use since then.[113] PFAS are also used to improve the stability of the baths used in electroplating of copper, nickel and tin and the overall performance of the process. In addition, PFAS are used to treat metal surfaces to prevent corrosion, reduce mechanical wear, or enhance aesthetic appearance, as well as to promote flow of metal coatings and prevent cracks during drying.[114]

The chrome plating industry is estimated to use around 32 to 40.7 tonnes of pure PFOS globally. The estimations are likely to cover different applications within metal plating, and not only chromium plating.[115] For Denmark, this number was estimated to be 10 kg/year in 2009 with 28 kg/year as purchased quantity.[116] In Sweden, the figure (from 2013) was 180 kg/year for PFOS.[117]

Again, the proportion of metal plating facilities in Europe using PFAS is not known. Statistics from Eurostat[118] on the number of establishments of treatment and coating of metals and machining in the EEA indicate 163 establishments with more than 250 employees in 2015, and another 151,455 establishments with less than 250 employees, i.e., SMEs.

Paper and paper products

Paper mills and paper products industry using PFAS to produce waterproof and greaseproof paper products may be a significant source of PFAS contamination released to water and air as well as to soil.[119] For example, a mapping of PFAS pathways to Norway's Tyrifjorden identified paper mills as among the main sources of the fjord's PFAS contamination. As per Case Study 4.5.2.1 below, paper mill waste has also been implicated in PFAS-contaminated substrate sold as compost.

The PFAS are typically added to wet wood fibers that are subsequently made into paper. A US NGO obtained notifications to the US Food and Drug Administration concerning PFAS for use in food contact materials.[120] The FDA notifications estimated releases to the environment of the PFAS based on a *typical paper mill producing 825 tonnes of PFAS-coated paper per day and discharging 26 million gallons (around 99,000 m^3) of water per day*. One notification from the company Chemours estimated wastewater discharges of 95 pounds/day (43 kg/day–15,965 kg/y) in discharges contain-

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[112] German Environment Agency (2017). Use of PFOS in chromium plating – Characterisation of closed-loop systems, use of alternative substances. Report No. (UBA-FB) 002369/ENG.

[113] Danish Environmental Protection Agency (2011). Substitutions of PFOS for use in non-decorative hard chrome plating.

[114] Kissa E (2001). Fluorinated Surfactants and Repellents. Surfactant Science Series. 97. Marcel Dekker, New York

[115] Danish Environmental Protection Agency (2011). Substitutions of PFOS for use in non-decorative hard chrome plating.

[116] Ibid.

[117] Hansson *et al.* (2016). Sammanställning av befintlig kunskap om föroreningskällor till PFAS-ämnen i svensk miljö. Report Number C 182.

[118] Eurostat Annual enterprise statistics by size class for special aggregates of activities (NACE Rev. 2) [sbs_sc_sca_r2].

[119] Neltner T and Maffini M, Paper mills as a significant source of PFAS contamination, but who's watching? EDF, 21.05.2018 Accessed 10.11.2018.

[120] Ibid.

ing 43,000 ppt. Another notification for the same PFAS estimated higher concentrations in the paper, resulting in 183 pounds/day (83 kg/day–30,295 kg/year) and wastewater discharges containing concentrations of 83,000 ppt.

Paper and cardboard treated with PFAS are frequently used in products such as plates, popcorn bags, pizza boxes, and food containers and wraps (see Case Study 4 on food contact materials). Non-food applications may include folding cartons and masking papers.[121]

Statistics from Eurostat[122] on the number of manufacturers of paper and paper products in the EEA provide totals of 488 manufacturers employing more than 250 employees in 2015, and another 19,477 establishments with less than 250 employees, i.e., SMEs. It is not known how many of these manufacturers use PFAS to treat their products.

Paints and varnishes

PFAS have long been used in coating, paint, and varnish to reduce surface tension for substrate wetting and levelling, as dispersing agents, and for improving gloss and antistatic properties. The protective properties of anticorrosive paints can be enhanced by perfluorinated urethanes. PFAS can also be used as aids in pigment grinding and to address pigment flotation problems.[123]

Eurostat statistics[124] indicate that 104 manufacturers of paints and varnishes in the EEA employ more than 250 employees in 2015, and another 4,027 establishments employ less than 250 employees. Again, it is not known how many of these use PFAS surfactants in their products.

Cleaning products

The surfactant properties of PFAS have made them useful in industrial and household cleaning products. They have been used to lower surface tension and improve wetting and rinse-off in products such as carpet spot cleaners, alkaline cleaners, denture cleaners and shampoos, floor polish, and dishwashing liquids. They are sometimes added to cleaners containing strong acids and bases, such as those for cleaning concrete, masonry, and metal surfaces (e.g. airplanes). They may also be used in nonaqueous cleaning agents to aid in removal of adhesives and in dry cleaning of textiles or in the cleaning of metal surfaces. PFAS can also enhance cleaning formulations for removal of calcium sulfate scale from reverse osmosis membranes.

The relevant Eurostat category here is "Manufacturers of soap and detergents, cleaning and polishing preparations, perfumes and toilet preparations".[125] Under this category, some 178 manufacturers in the EEA employ more than 250 employees in 2015, and another 9,402 establishments employ less than 250 employees. Again, it is not known how many of these use PFAS surfactants in their products.

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[121] Kissa E (2001). Fluorinated Surfactants and Repellents. Surfactant Science Series. 97. Marcel Dekker, New York.

[122] Eurostat Annual enterprise statistics by size class for special aggregates of activities (NACE Rev. 2) [sbs_sc_sca_r2].

[123] Ibid.

[124] Ibid.

[125] Ibid.

Plastics, resins, and rubbers

PFAS are used to manufacture certain plastics or applied plastics such as polytetrafluoroethylene (PTFE) and polyvinylidene fluoride (PVDF). PTFE is best known by the brand name Teflon (Dupont, now Chemours). It has hundreds of uses in consumer and industrial products such as textiles, medical equipment, cookware, and so on.

PVDF is used in a range of industrial applications such as automotive fuel hoses, electrical cable insulation and jacketing, high purity piping, and semiconductor piping.[126] They are also used as mold-release agents for thermoplastics, polypropylene, and epoxy resins, polyurethane elastomer foam molding, in formulations for antiblocking agents for vulcanized and unvulcanized rubbers, in silicone rubber sealants for soil resistance, and to improve wetting of fibers or fillers in composite resins.[127]

The closest Eurostat category here is "Manufacturers of basic chemicals, fertilisers and nitrogen compounds, plastics and synthetic rubber in primary forms".[128] Under this category, 340[129] manufacturers in the EEA had more than 250 employees in 2015, and another 8,650 establishments employ less than 250 employees. Again, it is not known how many of these are manufacturers using fluorochemicals or fluoropolymers.

Car washes

The surfactant properties of PFAS make them useful for a wide range of industrial cleaning products and surface treatments. For example, they are used in car wash products and automobile waxes, which makes car washes potential sources of PFAS contamination.
In 2018, a car wash facility in the US state of New Hampshire was cited as one of the sources of PFAS contamination in wells serving several nearby towns.[130] Investigators tested wells on the car wash property and found levels for PFAS higher than expected – up to 158.8 ppt, compared to the USEPA lifetime advisory level of 70 ppt. The facility will be required to take measures to prevent the contamination from continuing.

According to the International Car Wash Association 79,000 car wash facilities are operating in Europe. These are likely to be SMEs employing less than 250 workers.[131] It is not known how many of these that use products containing PFAS.

Manufacturers of PFAS-treated products – data limitations and assumptions

Table 11 present the number of manufacturers carrying out activities that may involve the use of PFAS. These statistics are taken from Eurostat and, in the case of car washes, from the industry trade association. The numbers in column 1 represent small-sized manufacturers with less than 250 employees, while column 2 represent medium-sized-manufacturers with more than 250 employees.

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[126] The European Commission-DG Enterprise and Industry (2010). Analysis of the risks arising from the industrial use of Perfluorooctanoic acid (PROA) and Ammonium Perfluorooctanoate (APFO) and from their use in consumer articles.

[127] Kissa E (2001). Fluorinated Surfactants and Repellents. Surfactant Science Series. 97. Marcel Dekker, New York.

[128] Eurostat Annual enterprise statistics by size class for special aggregates of activities (NACE Rev. 2) [sbs_sc_sca_r2].

[129] Figures for CZ, IE, EL and SK are missing for entreprises with 250 or more employees.

[130] Sullivan M, Car wash cites for PFAS pollution, Sea Coast Online, June 4 2018. Accessed 19 August 2018.

[131] International Car Wash Association. Industry Information.

Table 11: Number of manufacturers carrying out activities that may have involved use of PFAS

Industrial activity	Manufacturers <250 employees	Manufacturers >250 employees
Textiles	61,685	262
Leather	37,120	159
Carpets	no data	-
Paper	19,477	488
Paints and varnishes	4,027	104
Cleaning products	-	178
Metal treatments	151,455	163
Car washes	79,000	-
Plastic, resins, rubbers	-	340
Totals	352,764	1694
3% of total	10,583	51
10% of total	35,276	169

It is not known how many of the products manufactured by these companies that have been produced or treated with PFAS, or how many commercial service industries that are using products containing PFAS. In the absence of more data, it was assumed that between 3% and 10% of the manufacturers in these industries have used or are using PFAS in the manufacturing process or in the commercial service provided. These activities would have the potential for releasing PFAS to air, water and soil during the manufacturing process as well as afterwards, in the form of industrial waste.

Note that these numbers do not include manufacturers from other industrial activities known to use PFAS, such as makers of electronic chips, cosmetics and personal care products, photography films and mineral extraction. Note also that non-fluorinated alternatives are available for some of these applications, e.g., the consumer textile industry.

4.3 Case Study 3: Contamination from use of aqueous film-forming foams

4.3.1 Background and context

Aqueous film-forming foams (AFFFs), a specific sub-type of firefighting foam[132], are one of the many industrial products that contain PFAS. PFAS-containing AFFFs were found to be particularly useful in extinguishing petroleum-based fires (also known as class B liquid fires).[133] The surfactant properties of the PFAS serve to form a coating or blanket that deprives the fire of oxygen until the flames die out. Because of their

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[132] Norden (2013). Per- and polyfluorinated substances in the Nordic Countries: Use, occurrence and toxicology. TemaNord 2013:542.

[133] Swedish Environmental Institute (2015). Risks and Effects of the dispersion of PFAS on Aquatic, Terrestrial and Human populations in the vicinity of International Airports: Final Report of the RE-PATH project. p.17.

effectiveness, they have been widely used around the world since the 1960s[134] both at airports and at fire training facilities.

The biggest concern related to the use of AFFFs is the contamination of drinking water sources.[135] This concern is also related to long-lasting impacts of these substances in the water. For instance, PFOAs are said to have a hydrolytic half-life of more than 97 years.[136] Contamination of the environment due to AFFFs might take place in different ways in specific locations due to local, complex interactions within the ecosystems. Various exposure pathways have been identified.[137]

The hazardous substances in the AFFFs usually find their way to surface waters through direct runoff, in ground waters through infiltration and in soil through soil diffusion or dispersion. Drinking water can be contaminated as a result of ground water and surface water contamination.[138] Groundwater and surface water contamination can also lead to contamination of agricultural produce through uptake into biota. Contaminated surface waters and biota (fish) can create further health risks for humans and other animals.[139] A Swedish study ("RE-PATH") investigated contamination around two airports where AFFFs had been used for many years.[140] The results clearly indicated increased levels of PFAS in the surrounding soil, surface/ground water and biota – up to 100 times higher than in control areas.

Water pollution (whether it is groundwater or surface waters) related to the use of AFFFs following a fire, accidental leaks or fire-fighting trainings is considered to be severe.[141] Cases of groundwater, soil and surface water contamination have been documented near airports, military bases and fire drill sites in Germany, the Scandinavian countries[142], the UK and others. One report suggests that *many classes of PFAS are observed in groundwater, essentially every AFFF impacted site investigated to date.*[143]

As the environmental and health risks of PFAS became apparent in the 1980s, the role of AFFFs in PFAS-related environmental contamination started to draw attention. In Europe, AFFFs containing PFOS were banned in 2006 with a complete phase-out in

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[134] Kärrman A *et al.* (2011). Environmental levels and distribution of structural isomers of perfluoroalkyl acids after aqueous fire-fighting foam (AFFF) contamination. Environ. Chem., 8, 372–380.

[135] Field, J *et al.* (2017). FAQs Regarding PFAS Associated with AFFF Use at U.S. Military Sites, Report for Environmental Security Technology Certification Program (ESTCP).

[136] Franko *et al.* (2012). Dermal Penetratoi potential of Perfluorootanoic Acid (PFOA) in Human and Mouse Skin, Journal of Toxicology and Environmental Health, Part A. 75:50–62.

[137] The National Academies of Science Engineering and Medicine (2017). Use and Potential Impacts of AFFF Containing PFAS at Airports.

[138] Interstate Technology Regulatory Council (no date). Environmental Fate and Transport for Per- and Polyfluoroalkly Substances.

[139] The National Academies of Science, Engineering, Medicine (2017). Use and Potential Impacts of AFFF Containing PFAS at Airports.

[140] Swedish Environmental Protection Agency (2015). Risks and Effects of the dispersion of PFAS on Aquatic, Terrestrial and Human populations in the vicinity of International Airports: Final Report of the RE-PATH project. Report number: B 2232.

[141] Eschauzier C *et al.* (2012). Polyfluorinated Chemicals in European Surface Waters, Ground and Drinking Waters. In: Knepper T., Lange F. (eds) Polyfluorinated Chemicals and Transformation Products. The Handbook of Environmental Chemistry, vol 17. Springer, Berlin, Heidelberg.

[142] Danish Environmental Protection Agency (2014). Screeningsundersøgelse af udvalgte PFASforbindelser som jord- og grundvandsforurening I forbindelse med punktkilder (In Danish).

[143] Field J *et al.* (Report for Environmental Security Technology Certification Program-ESTCP) (2017). FAQs Regarding PFASs Associated with AFFF Use at U.S. Military Sites. p:8.

2011.[144] Starting from 2020, the use of AFFFs containing more than 25 ppb of PFOA or its salts as well as those containing more than 1000 ppb of one or a combination of PFOA related substances will be restricted within the EU.[145] The restrictions will not apply to AFFFs placed on the market before July 2020.[146]

The new generation of AFFFs may still contain shorter chain PFAS.[147] However, only limited data is available on the chemical composition of these newer generation AFFFs, previous studies found high concentrations of PFHxA, C6 and 6:2 FTS in the products.[148] Little information is also available for the impact of these fluorinated replacement substances on the environment and human health. Furthermore, because the older generation PFAS (such as PFOS) are highly toxic and persistent; the impacts of the historical releases continue to present serious risk to human health and to the environment. On the positive side, high-performance non-fluorinated AFFFs have been developed and are now on the market.[149]

4.3.2 Cases of contamination

Kallinge-Ronneby Military and Civilian Airbase

Between 1980 and 2003, AFFFs containing PFOS were used in Sweden. In 2003, these were replaced a new type containing other PFAS but old stocks containing PFOS continued to be used.[150] Swedish airports and Swedish armed forces started using a fluorine-free alternative to fluorine-based fire-fighting foams as of June 2011.[151]

During a 2013 groundwater quality survey, high concentrations of PFAS were detected in the Bredåkra delta (Ronneby). The testing was expanded to a larger area, confirming the PFAS contamination in the outgoing water from one of the two municipal waterworks, Brantafors, which supplied water to around 5,000 people.[152]

Table 12 presents the levels for some of the PFAS compounds detected in Brantafors compared to Kärragården, the second source of drinking water in the municipality. It can be seen that PFHxS, PFOA and PFOS were sometimes 100–300

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[144] Swedish Chemicals Agency (2015). Survey of Fire Fighting Foam.

[145] Commission Regulation (EU) 2017/1000 of 13 June 2017 amending Annex XVII to Regulation (EC) No 1907/2006 of the European Parliament and of the Council concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) as regards perfluorooctanoic acid (PFOA), its salts and PFOA-related substances.

[146] Ibid.

[147] Swedish Environmental Protection Agency (2015). Risks and Effects of the dispersion of PFAS on Aquatic, Terrestrial and Human populations in the vicinity of International Airports: Final Report of the RE-PATH project. Report number: B 2232.

[148] Swedish Chemicals Agency (2014). Chemical Analysis of Selected Fire-fighting Foams on the Swedish Market.

[149] IPEN (2018). Fluorine-free firefighting foams (3f) viable alternatives to fluorinated aqueous film-forming foams (AFFF).

[150] Swedish Environmental Protection Agency (2015). Risks and Effects of the dispersion of PFAS on Aquatic, Terrestrial and Human populations in the vicinity of International Airports: Final Report of the RE-PATH project. Report number: B 2232.

[151] Swedish Chemicals Agency (2015). Occurrence and use of highly fluorinated substances and alternatives: Report from a government assignment. Report 7/15.

[152] Ronneby Municipality Website, page dedicated to PFAS contamination, available here.

times higher in the contaminated water source. Given that firefighting foams containing PFOS were phased out between 2003 and 2008[153], these highly elevated levels underline the persistent nature of PFAS.[154]

Table 12: PFAS levels (ng/l) in outgoing drinking water from the waterworks in Ronneby, Sweden on Dec 10, 2013

	Brantafors	Kärragården	
PFPeA (Perfluoropentanoic acid)	38	10	The Swedish National Food Agency sets the recommended action level of 90 ng/l for a combined sum for 11 different PFAS, highlighted in red in the table.
PFHxA (Perfluorohexanoic acid)	320	3.6	
PFHpA (Perfluoroheptanoic acid)	32	1.4	
PFOA (Perfluorooctanoic acid)	100	1	
PFBS (Perfluorobutane sulfonic acid)	130	<2.6	
PFHxS (Perfluorohexane sulfonic acid)	1700	4.6	
PFOS (Perfluorooctane sulfonic acid)	8000	27	
PFHpS (Perfluoroheptane sulfonic acid)	60	<1	

Source: University of Goteborg, The Sahlgrenska Academy of Instutite of Medicine (Li Ying *et al.*), Technical Report: Half-lives of PFOS, PFHxS and PFOA after end of exposure to contaminated drinking water, 2017.

The source of the contamination was identified as the fire drill site located in the nearby military airport.[155] The contamination is estimated to have started in the mid-1980s.[156] The quantity released into the environment is unknown. The PFAS leaked from the site to the surrounding area into soil, eventually reaching the ground waters. The contaminated water source was equipped with a carbon filter at the time and according to the authorities, this filtering system might have reduced contamination of the drinking water, until it became saturated.[157]

Brantafors waterworks was closed right after the contamination was detected, and reopened a year later in 2014 after being equipped with charcoal filters and using only two of its four abstraction points (the remaining two having too high levels of PFAS). The water was monitored until October 2014, when the PFAS levels showed an upgoing trend which led to the re-closing of the waterwork, despite levels never exceeding the Swedish recommended action level of 90 ng/l. To secure drinking water supply, new pipes were built to provide Brantafors with uncontaminated water from the area Karlsnäs.

Biomonitoring between 2014 and 2016 resulted in testing of 3418 persons to determine exposure to PFAS from the drinking water. In addition, a smaller sub-sample of 106 individuals was created for a panel study to estimate half-life of the substances. These individuals gave regular blood samples and the monitoring will continue in the

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[153] Banzhaf S *et al.* (2016). A review of contamination of surface-, ground-, and drinking water in Sweden by perfluoroalkyl and polyfluoroalkyl substances (PFASs). The Royal Swedish Academy of Sciences. p.337.

[154] Li Ying *et al.* (2017). Technical Report: Half-lives of PFOS, PFHxS and PFOA after end of exposure to contaminated drinking water.

[155] Swedish Chemicals Agency (2015). Survey of Fire Fighting Foam.

[156] Li Ying *et al.* (2017). Technical Report: Half-lives of PFOS, PFHxS and PFOA after end of exposure to contaminated drinking water.

[157] Ronneby Municipality Website, page dedicated to PFAS contamination, available here.

coming years.[158] The concentrations for the Ronneby main group and for the sub-group were much higher when compared to the reference group, a sample of 242 people living in a nearby community not affected by the contamination, see Table 13.

Table 13: Median levels for PFAS concentrations in ng/ml in serum samples, tested 6th months after end of exposure

Contaminants	Reference Population (n=242)	Main Ronneby Group (n=3418)	Panel Study Group (n= 106)
PFHxS	0.84	152	277
PFOA	1.59	10.4	17.5
PFOS	4.21	176	345

Source: University of Goteborg, The Sahlgrenska Academy of Instutite of Medicine (Li Ying *et al.*), Technical Report: Half-lives of PFOS, PFHxS and PFOA after end of exposure to contaminated drinking water, 2017

Another pilot study was conducted among school children comparing those who had been drinking the contaminated water and those who had not. The children exposed to contamination were found to have 20–50 times higher levels of different PFAS substances, particularly PFOS, PFOA and PFHxS.[159]

Ronneby and other incidents led the Swedish authorities and other responsible parties (like the Swedish Air forces) to conduct national scale monitoring of drinking waters as well as further investigations in known contaminated areas.[160] The Swedish Chemical Agency (KEMI) and the National Food Agency set up a national PFAS network which brings together a wide range of stakeholders to advance existing knowledge on the issue.[161] In one of the few examples of national monitoring of PFAS in the environment, around 6,000 measurements of surface and ground water were compiled (existing data or new measurements) across the county by the Swedish Environmental Protection Agency. All water supplies with contamination levels that exceeded the safety level of 90 ng/l were found to be located close to an individual fire training site or to one located within an airport. The use of fire extinguishing foams was identified as the *largest direct point source* of contamination.[162]

Between 2013 and 2015, new water pipe connections were built between uncontaminated wells in Karlsnäs and Brantafors.[163] The cost of changing the water supply from Brantafors to Karlsnäs is roughly estimated to have cost Ronneby municipality

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[158] Li Ying *et al.* (2017). Technical Report: Half-lives of PFOS, PFHxS and PFOA after end of exposure to contaminated drinking water.

[159] Jakobsson K *et al.* (2014). Exponering för perfluorerade ämnen (PFAS) i dricksvatten i Ronneby kommun (In Swedish). Rapport 8:2014.

[160] Banzhaf S *et al.* (2016). A review of contamination of surface-, ground-, and drinking water in Sweden by perfluoroalkyl and polyfluoroalkyl substances (PFASs), The Royal Swedish Academy of Sciences.

[161] Sahlin S (2017). PFAS in the Baltic Sea Region.

[162] Swedish Environmental Protection Agency (2016). Högfluorerade ämnen (PFAS) och bekämpningsmedel en sammantagen bild av förekomsten i miljön. (report in Swedish with English Summary).

[163] Ronneby Municipality (No date). Frågor och svar om PFAS. Accessed August 2018.

SEK 60 million (incl. VAT) (EUR 5.8 million).[164] The additional annual cost for increased monitoring is calculated to around SEK 50,000 (incl VAT) (EUR 4,800).

According to the latest information available, the investigations are in progress as to how to clean up the contaminated soil in Ronneby. The Swedish Armed Forces is leading the process. Significant water resources remain unusable for an unforeseeable future due to PFAS contamination. The loss of these valuable resources has not been monetised, but should nevertheless be taken into account.

Jersey Civilian Airport, Channel Islands

The Jersey Airport case is one of the earliest and well documented examples in Europe of contamination of groundwater and surrounding areas due to AFFFs. In 1991, the fire training site started using AFFFs to meet the requirements of UK Airport Fire Services.[165] They were regularly using AFFFs until 1993, when foaming water started to emerge from a land drain excavated near the training site.[166] A *brown coloration and substantial foaming* was also identified in a farm's private water supply that was found to be contaminated.[167]

According to the accounts of the airport, 78 properties were within the plume area. Groundwater in 36 of these properties tested positive for PFOS.[168] Although at some of the sites, concentrations of PFOS have shown signs of decline, they have remained at high levels for seven years in private wells.[169] For instance, one private well continued to show high levels of PFOS since the first publicly available recording began in 1999 until 2006, between 2.7 µg/l (2700 ng/l) and 9.5 µg/l (9500 ng/l). In another area where samples were taken, one property had levels as high as 98 µg/l (98,000 ng/l).[170] As regards groundwater, the level detected in a borehole was 96 µg/l (96000 ng/l).[171]

The fire-training site was identified as the origin of the contamination. The foam used at the site during training exercises was discharged regularly without monitoring[172], dissolving into the ground and rainwaters.[173] Contamination subsequently found its way into the St.Ouen's aquifer and the beach of St.Ouen's Bay.[174]

A monitoring program was put in place to regularly test the ground waters for contamination levels, starting from 1994. The impact on agricultural products (potatoes

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[164] Schyberg, I. (2018). Ronneby Miljö och Teknik AB, personal communication.

[165] States of Jersey, States Greffe Logs, Jersey Airport: fireground remediation – Deed of settlement, 19 October 2004. Accessed 08.09.2018.

[166] Foundation for Water Research (2008). Survey of the prevalence of perfluorooctane sulphonate (pfos), perfluorooctanoic acid (pfoa) and related compounds in drinking water and their sources.

[167] States of Jersey, States Greffe Logs, Jersey Airport: fireground remediation – Deed of settlement, 19 October 2004. Accessed 08.09.2018.

[168] Jersey Airport Website dedicated to the PFOS, available here: http://www.jerseyairport.com/PFOS/Pages/Questions-and-Answers.aspx

[169] Foundation for Water Research (2008). Survey of the prevalence of perfluorooctane sulphonate (pfos), perfluorooctanoic acid (pfoa) and related compounds in drinking water and their sources.

[170] Ibid.

[171] Ibid.

[172] Robins N S (British Geological Survey)(2000). The water resources of Jersey: an overview.

[173] States of Jersey, States Greffe Logs, Jersey Airport: fireground remediation – Deed of settlement, 19 October 2004. Accessed 08.09.2018.

[174] Foundation for Water Research (2008). Survey of the prevalence of perfluorooctane sulphonate (pfos), perfluorooctanoic acid (pfoa) and related compounds in drinking water and their sources.

and cauliflowers etc.) was also analysed. At the time, the monitoring committee could not find any laboratory to test the relevant substances in Europe and the samples had to be sent to the US. In 1999 the authorities started to conduct their own analysis.[175] The initial response was to inform the residents using the water supplies of the possibility of contamination and to provide the particular farm mentioned above with a new borehole. Domestic water supplies were tested and free bottled water was offered in cases of contamination.[176] In the aftermath of the contamination, Jersey Airport has funded remediation and other related costs.[177] To ensure safe drinking water to the residents in the affected area, 67 among 78 properties in the plume area have been connected to the main water supply.[178]

Long-term remediation works began in 2002 and finished in 2004 with the aim of addressing the current contamination and preventing future problems.[179] The total cost was GBP 7.4 million (EUR 10.6 million). Table 14 presents the main breakdowns.

Table 14: Details of clean-up costs from the Jersey Civilian Airport

Expenditure Type	Total – Euros*
Investigation (incl. installing and monitoring boreholes, ongoing sampling and analysis)	1,427,167
Connection to water supplies	208,237
Payments of Water Rates to Jersey Water	523,386
Remedial Works associated to Old Fire Training Ground	446,739
Professional Fees	791,778
Finance Costs	122,282
Jersey Water Mains Connection Costs	808,303
Capital Works – Fire Training Ground	6,292,376
Total	10,620,271

Note The original figures were in British Pounds. They were converted to Euros using the rates from 19 October 2004, the day the Settlement Deed was approved between the parties involved.

Source: The Jersey Airport Website

Schiphol Airport, The Netherlands

In July 2008, an error in the sprinkler-system at a KLM hangar at Schiphol-Ost released 10,000 liters of aqueous fire-fighting foam, containing 143 kg of PFOS, into the surrounding environment.[180] This fed into a larger reserve of waste water (100 million liters) kept in five reserve reservoirs, several of which leaked and caused substantial contamination of the soil and surface water.[181] A later study found the water resources

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[175] Ibid.

[176] States of Jersey, States Greffe Logs, Jersey Airport: fireground remediation – Deed of settlement, 19 October 2004. Accessed 08.09.2018.

[177] According to the Jersey Airport Website, accessible here

[178] Jersey Airport Website dedicated to the PFOS, available here

[179] States of Jersey, States Greffe Logs, Jersey Airport: fireground remediation – Deed of settlement, 19 October 2004. Accessed 08.09.2018.

[180] Brandveilig, Zorgen om verontreiniging door incident met sprinklerinstallatie 07.09.2011 and No Author, Bodemvervuiling bij Schiphol snel aanpakken, De Volkskrant, 12 October 2011. Accessed 09.11.2018.

[181] The Government of Netherlands (2018). Beantwoording Kamervragen over berichten over met PFOS en PFOA verontreinigde grond bij Schiphol. (In Dutch).

to contain over 12 times the average amount of PFOS otherwise found in several reference sites in the Netherlands.[182] Residents were warned in 2008 not to swim in or consume fish from the nearby "Ringvaart" canal until the contaminated waste-water could be drained from the overfull reservoirs.[183]

Contaminated soil from this incident also resulted in delays of over a year to a project to build a new bus lane in Schiphol-Oost in 2017. Over 50,000 m^3 of the soil dug up was found to be contaminated and thus difficult to dispose.[184] The cost of the remediation is estimated at EUR 30–40 million.[185]

Information on AFFFs releases – data limitations and assumptions

According to the latest Eurostat data from 2015, Europe has a total of 455 civilian airports (28 MS and Iceland, Norway and Switzerland) with a passenger capacity of 15,000 and more per year), among those 318 are considered main airports with 150,000 or more passengers by year.[186]

On-line country by country research found an estimated 239 military airfields in the EEA countries and Switzerland.[187] The numbers are likely to be an underestimate, because they do not contain non-active military bases, which may be historical sources of AFFF contamination. Also, the US military uses firefighting foams during training and emergencies, as well as in automated fire suppression systems.[188] Under US military specifications, AFFFs purchased for use at US military sites must be based on PFAS chemistry to conform to military specifications (MIL-F-24385F).[189] Some military airfields in Europe would be in countries participating in NATO and therefore it is reasonable to assume that fluorinated AFFFs conforming to the US military specification have been used.

Countries have differed in their approaches to addressing problems related to the use of AFFFs. Swedish authorities developed guidance on how to avoid PFAS containing foams and how to handle residues from firefighting foams. The state-owned airport operator Swedavia went fluorine free as of 2008.[190] The Swedish Armed Forces still uses AFFFs, but only in one location (Halmstads Garnison) in which the foam and firewater is collected to avoid emissions to the environment.[191] The aim is to go completely PFAS free as soon as equally good alternatives are available. The Danish Armed Forces and the Royal Danish Air Force no longer uses fluorinated AFFFs, nor do the international airports in Copenhagen and Billund.[192] Only limited information has been found regarding

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[182] Kotterman MJJ and Kwadijk C.J.A.F (2009). PFOS onderzoek in waterbodem en vis. Report No: C064/09 (in Dutch).

[183] Sportvisserij Netherlands (News) Rijnland hervat waterafvoer Schiphol terrain, 21 July 2008, Accessed: August 2018. (In Dutch).

[184] Boele B, Schiphol Logistics Park blijkt vervuild, Haarlems Dagblad, 03.01.2018. Accessed 02.09.2018.

[185] Schiphol Airport (2017). Annual Report (In Dutch).

[186] Eurostat Transport Statistics [AIRP_TYP] Accessed 14/06/2018.

[187] These numbers are approximate and do not include all EU-28 MS. Some air fields might be inactive or no-longer in existence.

[188] Field J *et al.* (Report for Environmental Security Technology Certification Program-ESTCP) (2017). FAQs Regarding PFASs Associated with AFFF Use at U.S. Military Sites.

[189] Anderson H *et al.* (2016). Occurrence of select perfluoroalkyl substances at U.S. Air Force aqueous film-forming foam release sites other than fire-training areas: Field-validation of critical fate and transport properties, Chemosphere 150-678e685.

[190] Swedavia Airports (2018). PFAS på Swedavias flygplatser.

[191] Minister of Defence Hultqvist P. (2017) Answer to question on removal of PFAS. Dnr Fö2017/01275/MFI

[192] IPEN (2018). Fluorine-free firefighting foams (3f) viable alternatives to fluorinated aqueous film-forming foams (AFFF).

whether fluorinated AFFFs are used by municipal rescue services or what types of AFFFs are used at other Danish airports. In Finland, the military no longer uses AFFFs during training and fluorinated AFFFs are prohibited at the fire training areas of airports.[193]

In Norway, the state-owned Avinor (which operates the majority of Norway's civilian airports) abolished PFOS-containing fire foam in 2001, and went fluorine free in 2011.[194] The state-owned oil company Equinor has also shifted to fluorine free foams.[195] An important usage area remains offshore installations. Offshore platforms accounted for 54 out of 57.6 tonnes of PFOS released in Norway up until 2005 (the amounts released from airports and fire drilling areas on land could not be estimated).[196] The Norwegian offshore sector has now consciously reduced the amount of PFOS-containing foam – from 4 tonnes in 2014 to 1.1 tonne in 2017.[197]

In the UK, Heathrow Airport transitioned to fluorine free foam in 2012.[198] Though Germany has no national restrictions on the use of AFFFs, the Umweltbundesamt (UBA) has published guidelines on the issue and some federal states have set threshold values for PFAS in foams. The number of sites in the EEA where fluorinated AFFFs may have been used are presented in Table 15.

Table 15: The number of sites in the EEA where flourinated AFFFs may have been used.

Sector	Activity	Total
Aviation	Main passenger airports	318
	Medium passenger airports	137
	Small airports	no data
	Military airbases	239
Other fire control	Fire stations	84,099
	Site emergency services	no data

The number of fire stations across Europe is at least 85,000. However, it is not known whether all of these stations have been engaged in training involving AFFFs. The use of AFFFs, i.e., whether it is used during the trainings, accidents or both, might vary from country to country. A survey of AFFFs in Sweden by the Swedish Chemical Agency mentions firefighting training centres in Sweden, which used various types of AFFFs and notes that some types were not used after 2011 because they contained PFOS and PFOA.[199] An inventory carried out in 2017 aimed to locate all non-airport fire-fighting training sites in Norway active within the past 40 years, and identified 249 previously unknown sites.[200]

Another possible source of contamination is release of AFFFs during efforts to extinguish fires. Figures are available for different types of fires across the EU on a yearly

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[193] Sahlin S (2017). PFAS in the Baltic Sea Region.

[194] Avinor (2018). PFOS I Focus. (In Norwegian).

[195] IPEN (2018). Fluorine-free firefighting foams (3f) viable alternatives to fluorinated aqueous film-forming foams (AFFF).

[196] Climate and Pollution Agency (2012). Inventory of PFOS and PFOS-related substances in fire-fighting foams in Norway.

[197] A. Heggelund, Norwegian EPA (2018) Personal communication.

[198] Ibid.

[199] Swedish Chemicals Agency (2015). Survey of Fire Fighting Foam. Report 5/15.

[200] Heggelund, A. Norwegian EPA. Personal communication, Sep 2018.

basis (latest data from 2015) but AFFFs are specifically used to extinguish class B fires (fires involving gasoline, petroleum greases, tars, oils, oil-based paints, solvents, alcohols) and the number of class B fires could not be separated out from the total number of fires. Fluorinated AFFFs may also be present in fire suppression systems in place in industrial facilities where flammable and explosive substances are stored or used.

Some studies have tried to estimate the total amounts of AFFFs found in the market (sold, or in stocks of manufacturers as well as potential users like airports, firefighting training centres or petroleum refineries). For instance, a report from 2009 estimated the quantities of PFOS containing AFFFs sold in the Dutch market in 2002 as 212,000 l and concluded that around 25 million l of foam have been placed in the Dutch market in 20 years. Some 75% of these stocks were estimated as still unused. Around 18% of the stocks were thought to have been sold to the aviation industry, and another 11% sold to the fire prevention/protection industry.[201] Another study from 2008 estimated that in order to manufacture AFFFs between 1970 and 2002, 10,000 tonnes of POSF were produced/used. The amounts released into air/water were 9150 tonnes of POSF and between 91 to 460 tonnes of PFOS.[202] A more recent study estimated that between 1.13 to 3.81 tonnes of firefighting foam (monomers) is used annually in the EU.[203]

A recent US study identified 40 novel groups of anionic, zwitterionic and cationic PFAS that had been never observed before, using non-target screening of groundwater from the areas near 13 firefighting training sites. Water samples were collected between 2011 and 2015. Their chemical composition suggested that they were either produced via electrochemical fluorination (a process of manufacturing of AFFFs by 3M which was phased out in 2002) or were compounds found in AFFFs prior to 1988, for which the composition is not known.[204] It is therefore reasonable to assume that both previous and new generation AFFFs will continue to be a major source of pollution into the future.[205]

4.4 Case Study 4: Exposures during the use phase of PFAS-treated products

In order to have an overall view of the long-term costs of inaction, it is important to keep in mind the impact pathways of exposure from those products during the use phase of the PFAS life cycle. A 2000 3M study estimated that 85% of the indirect emissions of POSFs result from losses during the use and disposal stages.[206]

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[201] RIVM (2009). Estimation of emissions and exposures to PFOS used in industry. Report 601780002/2009.

[202] Alexandre G. Paul et al, (2008). A First Global Production, Emission, And Environmental Inventory For Perfluorooctane Sulfonate, Environmental Science & Technology 2009 43 (2), 386-392.

[203] Ministry of Infrastructure and Environment of Netherlands and Public Waste Agency of Flanders (2016). Inventory of awareness, approaches and policy: Insight in emerging contaminants in Europe.

[204] Krista A. Barzen-Hanson *et al.* (2017). Discovery of 40 classes of per- and polyfluoroalkyl substances in historical aqueous film-forming foams (AFFFs) and AFFF-impacted groundwater, Environmental Science and Technology.

[205] Banzhaf S *et al.* (2016). A review of contamination of surface-, ground-, and drinking water in Sweden by perfluoroalkyl and polyfluoroalkyl substances (PFASs), The Royal Swedish Academy of Sciences.

[206] Alexandre G. Paul *et al.* (2008). A First Global Production, Emission, And Environmental Inventory For Perfluorooctane Sulfonate. Environmental Science & Technology 2009 43 (2), 386–392.

A 2015 study by KEMI provides a useful compendium of PFAS in products[207] and lists a number of areas of application (see Table 16):

Table 16: Products and areas of applications for PFAS

Textiles and leather, including impregnating agents
Paper- and food-packaging
Fire-fighting foam
Cosmetic products
Household products
Paint, printing ink and lacquer
Cleaning agents and polish
Non-stick products
Ski wax
Hard- and decorative chrome plating
Hydraulic systems in the aviation industry
Photographic and electronic equipment and components
Photographic surface layers
Photoresistors and anti-reflective coatings for semiconductors
Synthesis chemicals (intermediates)
Medical devices
Building materials
Oil and mining production
Plant protection agents

For many of the applications above, the primary pathways of exposure will occur during the manufacturing of the product or at end-of-product disposal. For example, the application of PFAS as an anti-vapour suppressant during chrome plating will result in releases during the manufacture of the chrome-plated product, and virtually no PFAS will be released when the final product is being used or disposed of at end of life. The use of PFAS in manufacture of medical devices will similarly have the greatest impact during the manufacturing and disposal of the product. These impact pathways are addressed in Case Study 2 on manufacturing and Case Study 4 on end-of-life disposal.

However, for other products, the use phase will also have significant impacts on people and the environment, e.g., the use of PFAS in cosmetic products will have environmental impacts when the product is washed off by the user and the PFAS enters sewers, sewage treatment plants and eventually waterways. The laundering and re-impregnation of textiles and cleaning of leather treated with PFAS and the use of PFAS surfactants in cleaning agents or as agents in pharmaceuticals will likewise result in releases of PFAS to sewers and waterways.

This case study focuses on three categories of products containing PFAS where the use of the product leads to human exposure and to releases to the environment, where they then accumulate.

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[207] Swedish Chemicals Agency (2015). Occurrence and use of highly fluorinated substances and alternatives: Report from a government assignment. Report 7/15.

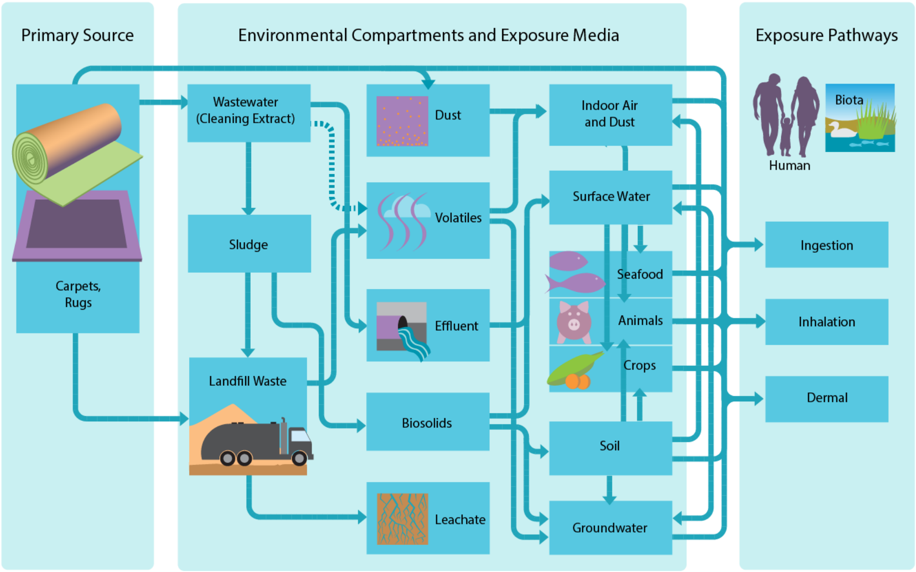
- PFAS-treated carpets
- PFAS-treated food contact materials
- cosmetic products containing PFAS.

It concludes with a look at how PFAS from both domestic and industrial sources will be collected into sewers and then channelled to urban waste water treatment plants where they end up in the wastewater discharges and sewage sludge.

4.4.1 Product 1 – PFAS-treated carpets

PFAS have been used to give stain, soil and oil resistance to carpets and rugs since the 1980s.[208] PFAS can be applied to carpets at four different points: (1) during the manufacture of fibers for carpets, (2) during the process of manufacturing carpets and rugs, (3) at a separate finishing facility after the carpet or rug has been manufactured, or (4) post-manufacture and sale through treatment by the consumer or professional cleaner.[209] Figure 4 show impact pathways for PFAS in carpets.

Figure 4: Impact pathways for PFAS in carpets



Source: From CA DTSC, 2018.

PFAS used to treat carpets and rugs is a major source of human exposure**.** Surface scuffing during normal use can release PFAS on fibers in the form of tiny particulates which can be resuspended and become part of indoor air and settle into dust. Human exposure takes place when these fine particulates are inhaled or when household or office

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[208] California Department of Toxic Substances Control (CADTSC) (2018). Product – Chemical Profile for Perfluoroalkyl and Polyfluoroalkyl Substances (PFASs) in Carpets and Rugs (Discussion draft).

[209] Note that stain-resistant sprays are also sold to consumers for treating upholstered furniture and other textiles.

dust is ingested. Exposure from treated carpets via ingestion is significantly higher in toddlers than adults because of greater hand-to-mouth behaviour.[210] Under one scenario, this pathway was estimated to contribute 40–60% of total uptake of PFAS in infants (0–1 years), toddlers (1–4 years), and children (5–11 years). Other vulnerable populations include industrial workers, carpet installers, carpet cleaners and workers in stores selling furnishings, carpets and outdoor clothing.[211]

Most commercial and residential carpets sold in the U.S. are treated with PFAS, especially carpets made of synthetic materials like nylon, polypropylene, acrylic and polyester, which are prone to absorbing liquids.[212] A 2000 study commissioned by 3M (a producer of PFAS treatments for carpets) estimated loss of PFAS from carpets at 50 percent over a typical lifespan of nine years, due to walking and vacuuming of the carpet.[213] After 2000, improvements made by PFAS-producers and carpet manufacturers considerably reduced the loss of fluorinated treatments.

After the US, the European Union is the second-biggest market in the world for carpets (both treated and untreated).[214] Belgium, the Netherlands and the United Kingdom are the leading countries where carpet manufacturing takes place. Some 1.6 million tonnes of carpet are disposed of in the EU each year. Most of this ends up being incinerated or deposited in landfills. Less than 3% of carpets marketed in the EU are subsequently recycled.

Side-chained fluorinated polymers are now the most commonly used carpet and rug PFAS treatment in the U.S. and in Europe. However, longer-chain PFAS continue to be manufactured in China, Russia and India, and carpets imported from those countries as well as carpets made from recycled materials may still contain long-chain PFAS.

A Danish survey of rugs marketed for children found PFAS in five of the 21 carpets screened for total-fluorine in the textile surface.[215]

4.4.2 Product 2 – Food contact materials treated with PFAS

PFAS are used in the paper industry for producing papers that resist grease and water. These are used for manufacturing food packaging, e.g. plates, popcorn bags, and

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[210] Trudel D *et al.* (2008). Estimating Consumer Exposure to PFOS and PFOA. Risk Analysis: An International Journal 28.2: 251–269.

[211] California Department of Toxic Substances Control (CADTSC) (2018). Product – Chemical Profile for Perfluoroalkyl and Polyfluoroalkyl Substances (PFASs) in Carpets and Rugs (Discussion draft).

[212] California Department of Toxic Substances Control (CADTSC) (2018). Product – Chemical Profile for Perfluoroalkyl and Polyfluoroalkyl Substances (PFASs) in Carpets and Rugs (Discussion draft).

[213] Battelle Memorial Institute 2000, as cited in CA DTSC, 2018.

[214] Onyshko, J and Hewlett R (Anthesis Consulting Group) (2018). Toxics in carpet in the European Union.

[215] Danish Environmental Protection Agency (2016). Survey and risk assessment of chemical substances in rugs for children.

other packaging materials, e.g., cartons, masking tape.[216] The end product may contain 1–1.5% PFAS by weight.[217] PFAS in food packaging can leach into food, increasing dietary exposure.[218]

Information on PFAS in paper- and food-packaging is hard to come by as it can be regarded as confidential business information. However, a recent U.S. study of food contact materials (FCM) used in fast food restaurants found detectable fluorine in 46% of food contact papers and 20% of paperboard samples analysed of the 400 samples analysed for total organofluorine content.[219] The presence of fluorinated chemicals in fast food packaging was seen as indicative of FCMs being a significant source of dietary PFAS exposure and environmental contamination.[220]

Similar levels of PFAS were found in fast food packaging gathered in Europe in 2017 and tested by the Danish Consumer Council's Think Chemicals programme.[221]

The use of PFAS in compostable food packaging might present an additional source of contamination for soil and vegetation.[222] Contamination of composts from PFAS and related substances has been documented.[223]

4.4.3 Product 3 – Cosmetic products containing PFAS

PFAS are used in various cosmetic and hygiene products such as sun screens, body lotions, shaving creams, dental floss and a variety of make-up products (e. g. lipsticks, eyeshadows).[224, 225] The use of PFAS in cosmetics is related to their surfactant qualities which help with the penetration of the products through the skin (such as creams) or their capacity to make the skin brighter and absorb[226] more oxygen. They are also used to make the cosmetic products oil- and water-repellent, and weather resistant.[227, 228]

Compared to other uses of PFAS such as in fire-fighting foams, research in the area of PFAS in cosmetics remains limited.[229] Information on the quantities of PFAS used in

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[216] Trier X *et al.* (2011). Polyfluorinated surfactants (PFS) in paper and board coatings for food packaging. Environ Sci Pollut Res Int 18(7):1108–1120. DOI: https://doi.org/10.1007/s11356-010-0439-3

[217] UNEP/POPS/POPRC.9/INF/11 2013.

[218] Begley TH *et al.* (2008). Migration of fluorochemical-paper additives from food-contact paper into foods and food simulants. Food Additive and Contaminants: Part A 25(3):384–390.

[219] Laurel A *et al.* (2017). Fluorinated Compounds in U.S. Fast Food Packaging. Environmental Science & Technology Letters.

[220] Tittlemier SA *et al.* (2007). Dietary exposure of Canadians to perfluorinated carboxylates and perfluorooctane sulfonate via consumption of meat, fish, fast foods, and food items prepared in their packaging. Journal of Agricultural and Food Chemistry. 55(8):3203–3210.

[221] Chemical Watch (10 March 2017)."High levels of fluorinated substances found in EU fast food packaging."

[222] Center for Environmental Health (2018). Avoiding Hidden Hazards.

[223] Fuchs Jacques G (FiBL) (2008). Compost and digestate: sustainability, benefits, impacts for the environment and for plant production.

[224] Fujii *et al.* (2013). Occurrence of perfluorinated carboxylic acids (PFCAs) in personal care products and compounding agents. Chemosphere 93 (2013) 538–544.

[225] Danish EPA. Risk Assessment of fluorinated substances in cosmetic products (Not yet published).

[226] Ibid.

[227] Fujii *et al.* (2013). Occurrence of perfluorinated carboxylic acids (PFCAs) in personal care products and compounding agents. Chemosphere 93 (2013) 538–544.

[228] Danish EPA. Risk Assessment of fluorinated substances in cosmetic products (Not yet published).

[229] Fischer S *et al.* (2016). Poly- and perfluoroalkyl substances on the market and in the Swedish environment. Norman Bulletin Issue 5.

cosmetic manufacturing is not available and cosmetic companies usually do not disclose information on the fluorine content.[230] The current body of knowledge about PFAS in cosmetics mostly stems from individual studies that surveyed a sample of products in the market to identify different types of PFAS in their composition.

Exposure to toxic substances in cosmetics can occur directly from the skin. For instance, a number of studies carried out on mice and human skin suggest that PFOA penetrates both human and mice skin.[231] Absorption of these chemicals through skin may not be a significant route of exposure, but absorption can increase when used on or around the eyes, posing a greater hazard.[232] Although the research in this area remains very limited, it has been suggested that significant variations in absorption may occur depending on the type of PFAS used in the products, and the other chemicals present.[233]

One of the PFAS identified in cosmetics is PTFE, known more widely under the brand name Teflon. The Skin Deep® database compiled and maintained by the U.S.-based Environmental Working Group provides ingredient lists and safety ratings for almost 75,000 cosmetics and personal care products.[234] Teflon was found in 66 different products from 15 different brands. In all, 13 different PFAS chemicals were found in nearly 200 products from 28 brands, including shampoo and shaving cream.

CosIng – the European Commission's public database on substances that may be found in cosmetic products – lists 76 PFAS.[235] Their technical functions lend them to a broad range of uses, such as anticaking agents, emulsifiers, anti-statics, emulsion stabilizers, surfactants, film formers, viscosity regulators and solvents. Many of the products are for use on the skin and hair. Chemicals used in personal cosmetics include perfluoropolyethers (PFPE), PFOA and perfluorodecaline.[236]

A survey of a wide range of consumer products by the Nordic Council of Ministers published in 2017 found concentrations of TOF (total organic fluorine) over the limits of detection for many of the products. The highest concentrations were detected in two dental floss samples (the only personal care products included in the sample). They both showed a 310,000,000 µg/m2 for TOF and 3 µg/m2 and 19.5 µg/m2 concentrations for PFAS respectively.[237] Table 17 shows the concentrations of different PFCAs detected.

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[230] Ibid.

[231] Franko *et al.* (2012). Dermal Penetratıon potential of Perfluorootanoic Acid (PFOA) in Human and Mouse Skin. Journal of Toxicology and Environmental Health, Part A. 75:50–62.

[232] EWG Cosmetics Database, Is Teflon in your Cosmetics? Published March 14, 2018. Accessed 08.08.2018.

[233] Ibid.

[234] EWG Cosmetics Database, Is Teflon in your Cosmetics? Published March 14, 2018. Accessed 08.08.2018.

[235] Swedish Chemicals Agency (2015). Occurrence and use of highly fluorinated substances and alternatives: Report from a government assignment. Report 7/15.

[236] Jamberg U and Holmstrom, K (2007). Perfluoroalkylated acids and related compounds (PFAS) in the Swedish environment.

[237] Nordic Council of Ministers (2017). Analysis of PFASs and TOF in products.

Table 17: PFCA concentrations (µg/kg) detected in dental floss samples

	PFBA	PFHxA	PFHpA	PFOA	PFNA	PFDA	PFUnDA	PFDoDA	PFTriA	PFTeDA
LOD[238]	0.05	0.10	0.06	0.06	0.08	0.08	0.08	0.05	0.05	0.09
Dental floss 1	< LOD	< LOD	< LOD	0.104	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD
Dental floss 2	< LOD	< LOD	3.47	13.1	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD
LOD	0.05	0.10	0.06	0.06	0.08	0.08	0.08	0.05	0.05	0.09

Source: Nordic Council of Ministers (2017). Analysis of PFASs and TOF in products.

A study carried out for a master's thesis at Lund University in 2017 investigated cosmetic products to identify PFAS. Products were grouped into larger categories as sunscreen, moisturizing creams, and foundation and eye make-up. PFAS were detected in 59 products among the 1354 surveyed (4.4% of total). The brands that had products for which tests showed PFAS content included L'Oréal (4 out of 41 products tested), IsaDora (8 out of 94), The Body Shop (18 out of 98), Maybelline (6 out of 72), Biotherm (1 out of 45), Lumene (22 out of 43). Large variations of PFAS concentrations among different brands were found.[239]

The Danish Environment Protection Agency carried out an ingredients survey based on the information found in the database of Kemiluppen app. The Kemiluppen app enables consumers to scan the barcodes of cosmetic products in Denmark, which are then assessed by the Danish Consumer Council. The survey evaluated 11,108 products that had been scanned (some products may have been scanned multiple times) and found 78 (in 20 different types of products) with fluoroalkyl substance or other fluorinated compounds listed as contents. It was also possible to gauge a product's market size, based on how many times consumers had scanned a particular product. PTFE (polytetrafluoroethylene) was present in 13 types of products that were scanned 16,641 times. C9-15 fluoroalcohol phosphate was present in four types of products that were scanned 7,826 times. Creams and lotions contained the highest number of fluoroalkyl substances (six), followed by BB/CC creams and foundations (three in each)

Another study conducted by the US Breast Cancer Fund found PFOS concentrations above detection levels in six out of 17 products tested, mainly anti-aging creams, moisturizers and skin powders, all belonging to the biggest manufacturers such as L'Oréal and Proctor & Gamble.[240] Perfluorinated compounds have also been found in hair and skin conditioners.[241]

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[238] LOD stands for level of detection.

[239] Henricsson C (Master Thesis) (2017). The Presence of PFAS in Cosmetic Products (Förekomst av PFAS i kosmetiska produkter). University of Lund.

[240] Breast Cancer Fund (2015). Anti-aging secrets exposed: chemical linked to breast cancer found in skin care.

[241] Nordic Ecolabelling (2018). About Nordic SAWN Ecolabelled Cosmetic Products. Version 3.3.

A campaign launched by a Swedish NGO in 2017 has resulted in six global cosmetic companies pledging to phase out the use of PFAS in their products.[242]

The use of personal care products leads to the products, after bathing, entering into sewerage and wastewater treatment plants. This type of contamination has received little attention, but in the case of products such as shampoos and shaving creams, it might be highly relevant. For example, one study found PFCA in 89% of the sunscreens surveyed.[243] This suggests that these products are potential contaminants for the aquatic environment.

The research carried out for this study was not able to find information on the quantities of PFAS used in manufacturing cosmetics. It is therefore not possible to provide an overall estimate of the scope of the problem. Though data is available on the concentrations of certain PFAS in the groundwater and drinking water systems, how much of this contamination stems from personal care products is unknown.

4.4.4 Discharges from waste water treatment plants

Conventional wastewater treatment is not effective in removing PFAS from waste streams.[244] Thus municipal wastewater treatment plants (WWTP) are major point sources for PFAS contamination of the aquatic environment.[245] The release of PFAS to the biosphere through WWTPs can be a result of both industrial activities and their domestic usage.[246] Given the extreme persistence of PFAS, these substances may end up in sewage sludge applied to agricultural land and subsequently taken up into produce for human consumption. One study found that

> "Often PFAS concentrations increase in wastewater treatment plants as a result of biodegradation of precursors during the activated sludge process. PFOA is generally fully discharged into receiving rivers, while about half of PFOS is retained in the sewage sludge."[247]

Other studies have confirmed this. A 2016 study for the Swedish Environmental Protection Agency concluded that the main transport route of PFAS from societal use of goods and chemical products into the environment was via sewage treatment plants and waste management facilities, which could constitute locally significant point sources. PFAS-containing sewage from industry could also enter the environment via sewage treatment and waste management facilities. For Sweden, emissions of PFAS into the environment

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[242] H&M, L'Oreal, Lumene, Body Shop, Isadora and Kicks. See: Chemical Watch: Cosmetics giant L'Oréal to eliminate PFASs in products, July 2018.

[243] Fujii *et al.* (2013). Occurrence of perfluorinated carboxylic acids (PFCAs) in personal care products and compounding agents. Chemosphere 93 (2013) 538–544.

[244] Adler, A and Van der Voet J (2015). Occurrence and point source characterization of perfluoroalkyl acids in sewage sludge, Chemosphere 129: 62–73.

[245] Ahrens L *et al.* (2016). Screening of PFASs in groundwater and surface water, Uppsala Report No: 2016:2 as cited in in CA DTSC, 2018.

[246] Eriksson U *et al.* (Report for Swedish Environmental Protection Agency) (2015). Screening of PFASs in sludge and water from waste water treatment plants.

[247] Loos *et al.* (2009; 2010), as cited in the Concawe report (2016). Environmental fate and effects of polyand perfluoroalkyl substances (PFAS).

from sewage treatment plants (336) were estimated at 70 kg/yr via water discharges and 5 kg/yr via sludge since 2004. The level in outgoing wastewater had increased since 2009, most likely due to an increase in the use of PFAS in consumer products.[248]

Another study from Switzerland detected PFAAs in all the sewage sludge samples collected from 20 different WWTPs in 2008 and tested a number of historical samples from 1993–2002. Concentrations of PFOS were between 15 to 600 µg/kg.[249] In the same vein, a study sampling sewage sludge from 45 different WWTPs in Switzerland found elevated PFOS concentrations (median 2290 µg/kg). In total, these 45 WWTPs constitute approximately ¼ of the total production of sludge in the country, with 55 000 tonnes. Total quantities of PFOS at the selected WWTPs was estimated as 7.5 kg for the year 2011 (median value), which is extrapolated as 30 kg per year for the whole country. Based on these findings, the study estimated per capita emissions for Switzerland (µg/pers/day) in sewage sludge, for PFOA and PFOS, as 0.2 and 4.8 respectively (median values). It is important to note that these WWTPs were selected for being close to potential industrial pollution sources and therefore the mean emissions might be overestimated.[250]

A study of several small rivers in Germany concluded that discharges of waste waters were the largest contributor of PFOS to surface waters. The study sampled waste water at different stages from treatment plants between 2005 and 2006.[251] The WWTPs had different industries in their proximity with different daily flows. The WWTPs received inflows from domestic, industrial (breweries, tabacco, food and plastics) and commercial sources, with domestic inflows having much lower levels of PFAS (PFOS and PFOA). The study also found that PFOA is able to pass fully from the WWTP without diminishing in concentration and to find its way to rivers, while half of the PFOS is retained in the sludge. In general the study states that PFOA concentrations found are similar to those reported for US, but PFOS concentrations were higher.[252]

In an Austrian[253] study, investigating concentrations of PFAS in effluent samples from 21 municipal WWTPs, findings indicate varying degrees of concentrations ranging from 0 to 280 ng/l for PFHxA, 10 to 220 ng/l for PFOA, and 4 to 340 ng/l for PFOS.[254]

A joint 2013 European study, analysed effluents from 90 European WWTPs, and concluded that despite the phasing out of PFOS, detection levels of this substance (among others) indicates an on-going release of these substances from PFAS containing products, and that release can be not *solely classified as historical*.

On the basis of these findings, it seems reasonable to conclude that PFAS concentrations are found in the discharges of most of Europe's wastewater treatment plants.

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[248] Swedish Environmental Protection Agency (2016). Högfluorerade ämnen (PFAS) och bekämpningsmedel en sammantagen bild av förekomsten i miljön (In Swedish).

[249] Adler A and Van der Voet J (2015). Occurrence and point source characterization of perfluoroalkyl acids in sewage sludge. Chemosphere 129: 62–73.

[250] Ibid.

[251] Becker M *et al.* (2008). Perfluoroactane surfactants in waste waters, the major source of river pollution. Chemosphere 72(1): 115–21.

[252] Ibid.

[253] The location of sampling sites is not mentionned in the study, but we assume it is Austria since the scientists publishing the study are based at the University of Vienna.

[254] Clara M *et al.* (2008). Emissions of perfluorinated alkylated substances (PFAS) from point sources-identification of relevant branches. Water Science and Technololgy 58(1):59–66.

4.5 Case Study 5: Impacts at end of life of PFAS-treated products

4.5.1 Background and context

At the end of their useful life, consumer products containing PFAS are discarded or, in some instances, recycled. If the product is a solution such as a cleaning fluid or coating, it will frequently be disposed of down a household drain where the PFAS will flow with the other fluids into a sewer system and to an urban waste water treatment plant.

If the product is an article, it will end up in a municipal solid waste stream. At that point it may be diverted for recycling or material reuse, or disposed of in a landfill or via an incinerator.

Globally, many municipalities and industries still rely on landfilling for final disposal of PFAS-containing products. The latest figures from the US EPA state that in 2015 53% of municipal waste was landfilled and 13% incinerated (the rest was recycled or composted).[255]

In the Nordic countries, landfilling household waste is done to a very low extent; e.g. 0.5% in Sweden (2017)[256], 1% in Denmark (2016)[257] and 3% in Norway (2017).[258] Incineration is the more common method for final treatment, with Sweden incinerating around 50% of its household waste in 2017, Denmark 51% (2016) and Norway 57% (2017). The EU-28 countries as a whole are also moving from landfilling to incineration. In 1995 64% of municipal solid waste was landfilled and 14% incinerated. In 2016, 24% of household waste went to landfills while 27% was incinerated.[259]

Knowledge about the necessary conditions for destruction of PFAS and what happens if those conditions are not achieved is still limited. PFAS can be broken down, but only under conditions that are so harsh, e.g. incineration at very high temperatures, that they do not occur in the normal environment.[260] A 2014 study for the USEPA found that a thermal reactor system operating at 1000 °C was able to destroy fluorotelomer-based polymers without resulting in the formation of detectable levels of PFOA.[261] However, such temperatures may not be typical. The EU rules for municipal waste incineration require a temperature of 850 °C.[262] Experiments in temperatures similar to municipal waste

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[255] Environment Protection Agency (2018). Advancing Sustainable Materials Management: 2015 Fact Sheet.

[256] Avfall Sverige (2018). Hushållsavfall – behandlad och insamlad mängd (In Swedish).

[257] Danish Environmental Protection Agency (2016). Affaldsstatistikken 2016 (In Danish).

[258] Statistisk sentralbyrå (2018). 426 kilo avfall per innbyggjar (In Norwegian).

[259] Calculated from Eurostat: Municipal waste landfilled, incinerated, recycled and composted in the EU-28, 1995 to 2016.

[260] Wang Z *et al.* (2017). A never-ending story of per- and polyfluoroalkyl substances (PFASs)?. Environmental Science & Technology, Mar 7;51(5).

[261] Taylor P S *et al.* (2014). Investigation of waste incineration of fluor4otelomer-based polymers as a potential source of PFOA in the environment. Chemosphere 110: 17–22.

[262] Directive 2010/75/EU of 24 November 2010 on industrial emissions (integrated pollution prevention and control) (Recast), OJ L 334/17 (17.12.2010). Article 50 requires operating conditions for a waste incineration plant to reach at least 850° C for at least two seconds.

incineration plants (800 °C -1000 °C) have shown that certain fluorine products remain after combustion.[263] The knowledge gap as regards the fate of these substances in incineration processes is significant and an area where the knowledge base needs to improve.

If a product is disposed of through landfill, the matrix (material of the product) may break down, but the PFAS will remain. Over time (and depending on the design of the landfill and the durability of the barriers between the waste and the underlying earth), the PFAS will migrate into any liquid in the landfill and drain into leachate collection systems or directly into soil and groundwater.

PFAS have been detected in landfill leachate around the world.[264] A Swedish study of 26 PFAS in samples from groundwater, surface water, WWTP effluent, and landfill leachate found that landfill leachates had the highest average total PFAS concentrations (487 ng/l).[265] Shorter-chain PFAAs tend to be the most abundant PFAS in landfill leachate.[266] Another factor raised by the study is that only a small fraction of the total number of PFAS compounds are being analysed. A screening of the total organic fluor (TOF) content in sewage sludge showed that the individually analysed PFAS compounds only accounted for a few percent of the TOF. The authors conclude that the picture is likely to be the same for landfill leachate.

PFAS release from solid waste is slow, compared to the amount of PFAS manufactured and used in consumer products each year. A study of PFAS releases from carpet and clothing using a model landfill reactor found that for the most part, the releases did not take place until >200 days of operation.[267] In an actual landfill, the process of breaking down the underlying substrate to release the PFAS will take much longer. Thus, the PFAS in solid waste sitting in landfills today will continue to be released into leachate for many years into the future.[268] Moreover, a review of the fate and transformation of PFAS in landfills noted that ambient air around landfill sites had found elevated concentrations of PFAS compared to upwind sites used as controls, which suggested that landfills are also potential sources of PFAS in the atmosphere.[269]

The stability of PFAS compounds also means that they tend to remain in other materials where they have been used. PFAS used to ensure low surface tensions during plastics moulding[270] are likely to remain in the plastic waste stream during materials recycling. This has implications for the circular economy.

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[263] Huber S *et al.* (Norwegian Institute for Air Research) (2009). Emissions from incineration of fluoropolymer materials. Report number: OR112/2009.

[264] Fuertes I *et al.* (2017), Perfluorinated alkyl substances (PFASs) in northern Spain municipal solid waste landfill leachates, Chemosphere 168: 399–407. See also Hamid H *et al.* (2018). Review of the fate and transformation of per- and polyfluoroalkyl substances (PFASs) in landfills. Environmental Pollution, 235: 74–84.

[265] Ahrens L *et al.* (2016). Screening of PFASs in groundwater and surface water, Uppsala Report No: 2016:2.

[266] Hamid *et al.* (2018).

[267] Lang J R *et al.* (2016). Release of Per- and Polyfluoroalkyl Substances (PFASs) from Carpet and Clothing in Model Anaerobic Landfill Reactors. Environmental Science & Technology, 50, 5024–5032.

[268] Lang J R *et al.* (2017). National Estimate of Per- and Polyfluoroalkyl Substance (PFAS) Release to U.S. Municipal Landfill Leachate. Environmental Science and Technology, 21;51 (4):2197–2205.

[269] Hamid H (2018). Review of the fate and transformation of per- and polyfluoroalkyl substances (PFASs) in landfills. Environmental Pollution, 235: 74–84.

[270] Kennebunk, Kennebunkort and Wells Water District (2017). Per and Polyfluoroalkyl Substances (PFASs) Usage (Draft for informational purposes). See also Hamid H (2018). Review of the fate and transformation of per- and polyfluoroalkyl substances (PFASs) in landfills. Environmental Pollution, 235: 74–84.

PFAS are frequently applied to paperboard used for food contact products, to make waterproof and greaseproof containers. For communities with active programs aimed at diverting biodegradable materials into composting systems, it has been an unwelcome surprise to learn that compost developed from feedstocks of mixed food and yard waste and including compostable food service ware may have high levels of PFAS, with the most prevalent being the short chain PFAS (C4 – C6).[271]

A Swedish study found that only a small fraction of the total number of PFAS compounds are being analysed. A screening of the total organic fluor (TOF) content in sewage sludge showed that the individually analysed PFAS compounds only accounted for a small percentage of the TOF.[272]

The application of compost or other soil enhancers such as biosolids (sewage sludge) in which PFAS are present to agricultural soil is leading to concern that the PFAS may be taken up by edible plants and end up bioaccumulating in the food chain. A study of greenhouse lettuce and tomatoes grown in a soil amended with biosolids affected by industrial chemicals found that the plants had taken up PFAS[273], and that perfluorobutanoic acid (PFBA) and perfluoropentanoic acid (PFPeA) seemed to have bioaccumulated to a degree. The short-chain PFAS seemed to be less attached (more mobile) to the agricultural soil and to have higher crop uptake potential. The study indicates that plants grown on soil amended with sewage sludge containing PFAS can bioaccumulate PFAS, with the extent of the bioaccumulation varying depending on the concentration of PFAS, the properties of the soil, the type of crop, and the chemical under analysis.

The finding that short-chain PFAS had the highest potential to bioaccumulate in produce was duplicated in a recent Minnesota study.[274] The study investigated whether home gardens irrigated with PFAS-contaminated water would result in contaminated produce. Among the conclusions: PFAS in water can enter into the food chain under real-world conditions. Short-chain PFAS in water had a greater impact on levels in produce than long-chain PFAS in soil. Finally, PFAS concentrations varied according to plant part with florets found to have the highest concentrations of PFAS.

4.5.2 Cases of contamination

Arnsberg, Germany

In 2006, a high level of PFAS contamination was detected in the conjunction of the rivers Rhine, Ruhr and Moehne as well as nearby public water supplies. This had consequences

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[271] Lee L and Trim H (2018). Summary Sheet Evaluating Perfluoroalkyl Acids in Composts with Compostable Food Serviceware Products in their Feedstocks.

[272] Avfall Sverige (2018). Hushållsavfall – behandlad och insamlad mängd (In Swedish).

273 Blaine AC *et al.* (2013). Uptake of Perfluoroalkyl Acids into Edible Crops via Land Applied Biosolids: Field and Greenhouse Studies. Environmental Science & Technology. 47(24), pp. 14062–14069.

[274] Scher D *et al.* (2018). Occurrence of perfluoroalkyl substances (PFAS) in garden produce at homes with a history of PFAS-contaminated drinking water. Chemosphere 196: 548–555.

for the whole Ruhr valley catchment and Lake Moehne, which supply 5–6 million people.[275] An estimated 40,000 people were exposed to drinking water that was contaminated from this source.[276] The water was contaminated with PFOA, perfluorohexanoate (PFHxA), perfluorohexane sulfonate (PFHxS), perfluoropentanoate (PFPA) and perfluorobutane sulfonate (PFBS). 110.5 kg of PFAS were calculated to have entered Lake Moehne.[277] This was gradually released into the Ruhr and Rhein, to make its way to the North Sea.

The source of the contamination was PFAS contaminated sludge containing industrial waste, which was sold under the name of "bio-solids" and was applied at farmland at the head of the Moehne valley.[278]

Several actions were taken to manage the contamination. First, a monitoring system was put into place to assess the level and spread of contamination in drinking water. Several biomonitoring studies were launched to measure the pathways into mothers and children (including breastmilk), and men, as well as the Activated carbon filters were installed in water works. Recommendations were developed to reduce the consumption of fish.[279] Carbon filters were installed in July 2006. The carbon filters were reactivated about every 6 months. The reactivation was undertaken in specialized centers that involved treatment of the filters in a furnace heated up to over 800 degrees Celsius.

A biomonitoring study was undertaken to determine the level of blood concentration in a sample of men, women and children.[280] In total, 138 children, mothers and men participated in the study. Measurements were taken before and in subsequent years after the installation of activated charcoal filtering system to remove PFOA from the drinking water. Repeat blood samples were analysed for about 20 to 25 individuals for each group (children, mothers and men). Notable decreases were detected over the two year period (see Table 18). For example, the serum concentration level of PFOA in children decreased 39%. The study suggest that the reduction may be due in part to a reduced consumption of fish from local sources.

Table 18: Relative reduction of PFC plasma levels (%) between 2006 and 2008

	PFOA	PFOS	PFHxS
Children	39.2 (31.6–48.5)	20.1 (14.7–27.6)	18.7 (10.4–33.7)
Mothers	39.4 (33.5–46.3)	21.7 (16.0–29.4)	29.6 (24.7–35.4)
Men	25.5 (21.3–30.5)	25.0 (21.5–29.0)	14.3 (10.4–19.7)

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[275] IPEN (2018). Fluorine-free firefighting foams (3f) viable alternatives to fluorinated aqueous film-forming foams (AFFF).

[276] Hölzer J *et al.* (2009). One-year follow-up of perfluorinated compounds in plasma of German residents from Arnsberg formerly exposed to PFOA-contaminated drinking water, International journal of hygiene and environmental health. 212(5), pp.499–504.

[277] Weber R (2016). Presentation for Science and Policy of Organohalogens pre-Dioxin Symposium.

[278] Skutlarek D *et al.* (2006). Perfluorinated surfactants in surface and drinking waters. Environmental science and pollution research international, 13(5), p.299. IPEN (2018). Fluorine-free firefighting foams (3f) viable alternatives to fluorinated aqueous film-forming foams (AFFF).

[279] WHO Europe (2016). Keeping our water clean: The case of water contamination in the Veneto Region, Italy.

[280] Brede E *et al.* (2010). Two-year follow-up biomonitoring pilot study of residents' and controls' PFC plasma levels after PFOA reduction in public water system in Arnsberg. International journal of hygiene and environmental health, 213(3), pp.217–223.

As of 2006, 100 million Euros had been spent on investments in the regional water works.[281] Charges were pressed against the German company providing the sludge, which declared bankruptcy as a consequence of the contamination scandal, and the CEO was taken to court. The following year, national monitoring activities by the competent authorities were initiated.

Baden-Wuerttemberg, Germany

Following the Arnsberg case (see previous case study), the state of Baden-Wuerttemberg analysed samples from 41 locations potentially subject to PFAS contamination in 2006.[282] Measure points with elevated levels were followed up subsequent years.

In 2013, PFAS was found during a routine analysis in a well belonging to Landkreis Rastatt's drinking water supply.[283] Further investigations unravelled a contamination situation of unprecedented dimensions, making it the greatest contamination case in Germany both in terms of surface affected and the complexity of contaminant composition.[284] As of August 2018, 644 hectares of soil in Landeskreis Rastatt and Stadtkreis Baden-Baden, as well as 240 hectares in Mannheim, are expected to be contaminated by PFAS.[285] Below the area affected runs one of the larges underwater rivers in Europe, the Oberrhein-Aquifer, adding to the level of graveness of the pollution incident.

Although the reason for contamination remains somewhat disputed, the explanation which mainly is put forward is the use of compost blended with contaminated paper mill waste which was applied on agricultural land between 2005 and 2008.[286] An additional source would be a fire extinguishing event in 2010. The total amount of PFAS which entered the environment is hard to appreciate; an (uncertain) estimate received from a member of staff at Landkreis Rastatt reads 1,000–5,000 kg.[287]

Following the PFAS discovery, two waterworks providing Rastatt drinking water were taken out of use due to PFAS in the water, leaving Rastatt with one single waterwork available. To ensure safe drinking water, the local water company Stadtwerke Rastatt has invested millions of Euros in new infrastructure, groundwater monitoring, treatment methods such as active carbon filters or reversed osmosis, and in securing alternative sources of water.[288] This has enabled one of the waterworks to reopen in Februari 2018. The reconstruction of pipes, water works, and installation of activated carbon filters have cost the company EUR 3.6 million by the end of 2017. The same activities are estimated to cost the company another EUR 6.2 million during 2018–2020

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[281] Weber R (2016). Presentation for Science and Policy of Organohalogens pre-Dioxin Symposium.

[282] LUBW (2018). Grundwasserüberwachungsprogramm Ergebnisse der Beprobung 2017 (in German).

[283] Regierungspräsidium Karlsruhe (No date). Überblick zur PFC-Problematik in Mittel- und Nordbaden.

[284] Regierungspräsidium Karlsruhe (2017). Antworten auf häufig gestellte Fragen zur PFC–Belastung im Landkreis Rastatt und den Stadtkreisen Baden-Baden und Mannheim Stand August 2017.

[285] Ministerium für Umwelt, Klima und Energiewirtschaft Baden-Württemberg (2018). Neuer Erlass schreibt Beurteilungsgrundlage für mögliche PFC-Belastungen von Grund- und Sickerwasser fort.

[286] Klatt P and Frey A (2016). Woher kam das Zeug bloß?, Frankfurter Allgemeine, 4 September 2016. Accessed September 2018.

[287] R. Söhlmann (2018). Landratsamt Rastatt, personal communication

[288] Stadtwerke Rastatt (2018). So schützen wir unser Trinkwasser in Rastatt (website in German) and personal communication

(much depending on how frequently the carbon filter will need to be changed). These costs have so far been borne by the company without the contribution of any state funds, and thus the water price for the consumers in Rastatt has been raised from EUR 1.64 to EUR 1.86 per m^3 in the course of 2017.

As regards the further securement of uncontaminated drinking water, there has been an ongoing discussion between the main water company (Stadtwerke Rastatt) and the responsible authorities at municipal and state level concerning the next steps to take. Though the water company called for immediate action in order to prevent a worsening of the situation, the public authorities proposed to spend the year up to 2021 to improve the knowledge base, and to await further action until then.[289] In the meanwhile, efforts to assess the extent and potential development of the contamination profile are being taken.

To improve knowledge on health effects, the state and local health authorities are carrying out a blood sampling study of the population, the results of which are scheduled to be presented at the end of 2018.[290] The study has cost around 257,000 Euros during 2017–2018, which includes costs for meetings with the experts, laboratory costs and the time spent on planning, carrying out and assessing the study. Two repetitions of the study are planned: one in 2020 and one in 2023, with an estimated budget of 408,000 Euro.

In the region in question, growing vegetables and fruit is a major part of the local economy. Today, even certain farmers who did not use the contaminated compost are unable to grow and sell their goods, as the PFAS has spread to reach their land as well.[291] To ensure that no produce with unacceptable levels of PFAS reach the consumers, the state of Baden-Wurttemberg has integrated a pre-harvest monitoring program targeting PFAS into their foodstuff monitoring framework. This is financed by the state and its costs have already amounted to more than one million Euros.[292] The state Environmental Department (LUBW) has also initiated pilot studies of PFAS in groundwater, focusing on potential contamination deriving from agriculture. As a result, PFAS were included into the regular state water monitoring program from 2015, with a planned timeline of four years. As of 2017, around 50% of the measure points showed PFAS contamination (around half of them at levels below 10 ng/l). Monitoring in general is likely to prove necessary for decades to come.

No clear verdict in terms of responsibility has yet been reached. Nevertheless, a verdict from Mannheim administrative court required the party who provided the contaminated compost to farmers in the region to pay for the preliminary investigation of the soils (35,000 Euros).[293] The court considered his provisioning of the papermill waste compost

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[289] Klatt P and Frey A (2016). Woher kam das Zeug bloß?, Frankfurter Allgemeine, 4 September 2016. Accessed September 2018.

[290] Gesundheitsamt Rastatt (No date). Informationen zum Stand der PFC-Blutkontrolluntersuchung im Landkreis Rastatt.

[291] Klatt P and Frey A (2016). Woher kam das Zeug bloß?, Frankfurter Allgemeine, 4 September 2016. Accessed September 2018.

[292] Ministerium für Umwelt, Klima und Energiewirtschaft Baden-Württemberg (No date). PFC-Belastung in Baden-Baden und im Landkreis Rastatt.

[293] Söhlmann, R. (2018), Landratsamt Rastatt. Personal communication.

mix to farmers as a cheap way of disposing of industrial waste, rather than providing useful soil improver. For the rest, the state has covered most of the costs related to the initial investigations and measures. 900,000 Euros has been spent on modelling groundwater remediation, and 1.5 million Euros on other research projects.[294]

As regards public spending, 4.4 million Euros of state funds and almost 1.7 million Euros of municipal funds have so far been used in relation to the PFAS contamination. How much expenses are yet to come remains unknown, but it has been estimated that a complete remediation of the affected soils might amount to 1–3 billion Euro.[295] A cost analysis dating from 2015 estimated that each hectare would cost 5.5 million Euros to remediate. With today's 640 contaminated hectares in Landkreis Rastatt, this would mean a total cost of around 3.5 billion Euro. To actually perform this enormous soil exchange is however not realistic, partly due to the vast quantities of soil that would be "lost".[296] In addition, the 2015 study estimated that the cost of groundwater remediation would amount to 150 million Euros. As today even more PFAS are likely to have reached the groundwater, it is probable that this figure will not suffice.

Rockford, Michigan

The leather tannery complex owned by the footwear company Wolverine World Wide treated leather for manufacturing into shoes sold under the brand HushPuppy. PFAS purchased from the company 3M were applied to the leather (along with other chemicals) and the shoes were marketed as being waterproof. The chemicals were stored in drums at outdoor locations. A 2000 summary of hazardous chemicals on site stated that 16,590 pounds (7,525 kg) of Scotchgard FC-3573 and 64,409 pounds (29,215 kg) of Scotchgard FX-3573 were kept on site. In the early 2000s, 3M reformulated its product (Scotchgard) to remove PFOS from the formulations because of evidence of the chemical's toxicity, bioaccumulability and persistence in the environment.

High concentrations of both PFOA and PFOS have now been found in soil and groundwater at the now unused manufacturing site, and the chemicals have now migrated into a creek that runs into the nearby Rogue River.[297] Testing of surface foam at a local dam also found very high levels of PFAS, as did testing of fish caught in the Rogue River. The State of Michigan has now issued a fish consumption advisory to warn local anglers not to eat fish from the most contaminated stretch of the river. In 2017 local residents alerted environmental authorities to a former licensed disposal facility owned and operated by Wolverine as well as several unregulated dumpsites where leather scraps and other manufacturing waste were deposited, and requested testing of nearby wells.[298] In May 2017, PFAS contamination was detected, and Wolverine began a more extensive well sampling program. It also started to provide bottled water and water filters for affected households.

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[294] Ministerium für Umwelt, Klima und Energiewirtschaft Baden-Württemberg (No date). PFC-Belastung in Baden-Baden und im Landkreis Rastatt.

[295] IPEN (2018). Fluorine-free firefighting foams (3f) viable alternatives to fluorinated aqueous film-forming foams (AFFF).

[296] Söhlmann, R. (2018). Landratsamt Rastatt, personal communication.

[297] See State of Michigan website on its PFAS response for more information.

[298] Ibid.

Later in 2017, the State of Michigan developed a groundwater criterion for PFOA and PFOS of 0.07 µg/l (70 ppt) for protection of drinking water.

In one of the areas close to the now closed landfill, 561 homes were tested for PFAS in drinking water; PFOA and PFOS was detected in 197 homes, 70 of which had concentrations over 70 ppt. The highest concentration found was 62,500 ppt. In another affected area, 690 homes were sampled, 391 had detected levels of PFOA and PFOS, 38 homes had concentrations over 70 ppt, and the highest concentration was 49,200 ppt.[299]

Blood tests of residents have shown high levels of PFAS. One long-term resident whose well tested at 38,000 ppt learned that four different PFAS were found in her blood for a combined total of 5 million ppt. One chemical, PFOS, was found at 3.2 million ppt – about 750 times the national blood level average of 4,300 ppt.[300] While it is not possible to pin specific health impacts to a specific exposure of PFAS, the resident knew of epidemiology studies that had found links to the thyroid problems she suffered from and the liver cancer from which her husband had died in 2016.

4.5.3 Extent of the exposure due to PFAS disposal to land

A study[301] of US municipal landfills calculated that the total mass of PFAS from landfill leachate to wastewater treatment plants in 2013 was between 563 and 638 kg. The researchers measured concentrations of 70 PFAS in 95 samples of leachate from 18 landfills in the USA of varying climates and deposit ages, then linked estimates of total annual leachate volumes in the US with the concentrations measured for the 19 PFAS where >50% of samples had quantifiable concentrations. Participating landfills were publicly owned, so they contained mainly municipal solid waste and some sewage sludge, but probably did not receive industrial waste. FTCA (5:3 fluorotelomer carboxylic acid) was the dominant PFAS in the majority of samples collected.

The ~600 kg/yr estimate for total PFAS mass release in US landfill leachate in 2013 has limitations. It is based on PFAS concentrations from 18 sites around the US, and then extrapolated to cover the total of 1540 landfills in the US that year. While none of the landfills in the study reported accepting waste from PFAS, textile or carpet production, some municipal solid waste landfills may accept such waste. For example, PFOS concentrations from leachate at a landfill that received wastewater treatment sludge from a 3M facility in Minnesota[302] were measured at 136 micrograms/L, compared to the ranges of concentrations (2–29 micrograms/L) in the leachate from the 18 landfills sampled in the study. In addition, it does not account for historic landfills (the US had some 6000 landfills in 1988) that may be unlined and

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[299] Ibid.

[300] Ellison G (2018). Belmont woman's blood is 750 times national PFAS average, Mlive, 11.01.2018 Accessed 15.10.2018.

[301] Lang JR *et al.* (2017). National Estimate of Per- and Polyfluoroalkyl Substance (PFAS) Release to U.S. Municipal Landfill Leachate. Environmental Science and Technology, 21;51(4):2197–2205.

[302] Oliaei F *et al.* (2013). PFOS and PFC releases and associated pollution from a production plant in Minnesota (USA). Environmental Science Pollution Research. 20: 1977–1992.

closed without low permeability covers.[303] These unlined landfills will continue to pose a risk of PFAS leakage to groundwater for many years to come.

The following examples illustrate that municipal and industrial landfills are sources of legacy PFAS, primarily affecting groundwater and run-off surface waters:

- a 2010 study calculated around 90 kg/yr for 44 PFAS in treated leachate from all (~1700) landfills in Germany[304];
- a 2016 study of PFAS in the Swedish environment from different sources estimated 70 kg/year of PFAS emissions via leachate from 365 landfills.[305] Except for 8 kg of PFAS spread to land, the leachate was sent for sewage treatment;
- a 2017 study of 4 municipal waste landfills across northern Spain gathered data on the occurrence and concentration of 16 PFAS in the leachate from those sites. The landfills served 1.8 million people. Based on the volume of leachates from the landfill sites, it was estimated that the combined discharge of the 16 PFAS was 1.2 kg/year.[306]

The costs of remediation for removing PFAS contamination from affected waters would therefore be the same as for other sources of PFAS contamination.

4.6 Other costs related to PFAS contamination

Some of the non-quantifiable costs of exposure to PFAS are the experiences of the individuals and communities affected, i.e., as they come to understand that the drinking water they have been consuming has contained a contaminant that may result in health impacts that do not become evident until years hence. Those experiences are part of the overall story concerning the socioeconomic costs of PFAS.

> "For years, folks trusted that their water providers were delivering a completely safe product and knew exactly what was in it. At the same time, the providers trusted that regulators were adequately protecting water sources and knew exactly what was in our rivers. That trust is gone."
>
> Editorial in *Wilmington NC Star News,* 24 June 2018[307]

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[303] Lang JR *et al.* (2017). National Estimate of Per- and Polyfluoroalkyl Substance (PFAS) Release to U.S. Municipal Landfill Leachate. Environmental Science and Technology, 21;51(4):2197–2205.

[304] Busch J (2010). Polyfluoroalkyl compounds in landfill leachates. Environmental Pollution, Vol 158:5 , 1467–1386.

[305] Swedish Environmental Protection Agency (2016). Högfluorerade ämnen (PFAS) och bekämpningsmedel en sammantagen bild av förekomsten i miljön.

[306] Fuertes I *et al.* (2017). Perfluorinated alkyl substances (PFASs) in northern Spain municipal solid waste landfill leachates. Chemosphere 168: 399–407.

[307] Editorial, We must take control of our water quality, Starnews Online, 25.06. 2018. Accessed 11. 09. 2018.

Other more quantifiable costs of inaction may include loss of property value, reputational damages to a polluting company, (e.g, the recent Miteni bankruptcy), court awarded damages and financial settlements. For example, the Australian government announced AU$73.1 million budgeted to support those affected by PFAS contamination, of which AU$55.2 million will be spent across five years to give people access to safe drinking water.[308] The government has already spent more than AU$100 million on PFAS, and has not yet started any remediation work. Some of the measures taken have addressed the human impacts of the contamination, e.g., public outreach, a help desk, and counselling services for affected communities.

Table 19 summarises a number of indemnities paid in legal settlements by companies with facilities that led to PFAS contamination of the environment as well as PFAS-related health effects.

Table 19: Amounts of some indemnities paid in legal settlement in relation to PFAS contamination due to different sources

Incident	Year[1]	Description	Amount (EUR)[2]
Contamination of drinking water in Hoosick Falls NY due to industrial production (US)	2014-Ongoing	Legal case on-going between the municipality and Saint-Gobain Performance Plastic and Honeywell International (as a part of on-going fees to be paid to the municipality)	443,000
Contamination of natural resources in Minnesota due to the 3M plant (US)	2018	Legal settlement between 3M and the State of Minnesota	710,400,000
Contamination of water supplies in Ohio (US)	2017	Agreement reached between Dupont Chemicals and Chemours in class action law suit with the residents	595,000,000
Contamination of Hyannis MA water supply due to AFFFs (US)	2017	Legal settlement between the town of Barnstable and Barnstable country	2,617,000
Contamination of agricultural fields in Baden-Wuerttemberg	2013	Initial investigations payed for by compost salesman who had provided contaminated compost to farmers	35,000

Note: 1) Year might refer to year of detection, or the year costs have incurred.
2) Costs in other currencies are converted to Euro, using average annual rates for the year they incurred.

4.7 Summary of case study findings

As the five case studies illustrate, PFAS are released to the environment from many sources, from production and manufacturing plants to specialist uses such as AFFFs for firefighting and everyday consumer products such as clothing, pizza boxes and cosmetics.

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[308] Swanson M, People, not politics, must be PFAS priority, The Herald, May 2018. Accessed 12.11.2018.

The first three case studies cover the activities that account for a large proportion of the PFAS released directly into the environment. Case Study 1 looks at how the industrial facilities producing the fluorochemicals and fluoropolymers, while relatively limited in number, are significant individual emitters of PFAS into the air, soil and waterways. The study estimates that 12 to 20 facilities actively produce fluorochemicals in Europe, that these facilities are significant sources of PFAS released to the environment, and that exposure to workers at these plants is high. The study did not identify fluorochemical production facilities in the Nordic countries.

Other industrial activities with the potential to release PFAS to the environment take place throughout Europe, including the Nordic region. Case Study 2 considers the manufacture and commercial use of PFAS-containing products, including textile and leather manufacturing; metal plating, including chromium plating; paper and paper product manufacturing; paints and varnishes; cleaning products; plastics, resins and rubbers; and car wash establishments. Releases of PFAS occur via the air or effluent entering sewerage and wastewater treatment plants, before discharge into waterways. The case study gathers Eurostat figures for the number of large companies and SMEs carrying out the industrial activities reviewed. In the absence of information concerning how many of the companies use PFAS in their manufacturing, a range of 3% to 10% of facilities is suggested.

The third major source of direct emissions is the widespread use of aqueous film-forming foams (AFFFs) used to extinguish fires in emergencies or during training, especially around airports and military bases. Where the AFFFs have migrated to groundwater and other sources of drinking water, nearby communities have been affected by elevated levels of PFAS in their drinking water. It is noted that other uses of AFFFs for firefighting, especially at major industrial facilities, may also be a significant source, but one that has so far received little attention. High performance non-fluorinated AFFFs are now available, but legacy emissions from PFAS in AFFFs used in the past will continue to be a problem for years to come.

The two case studies on the use and end-of-life phases of consumer products account for the remaining releases. They can be direct as well as indirect sources of exposure to PFAS. A 2000 study carried out for 3M estimated that 85% of the indirect emissions of POSFs (a precursor of PFOS) would result from losses during the use and disposal stages. More recent information on the proportion of indirect emissions of PFAS during the use and disposal stages of the chemicals' life cycle was not found.

Case Study 4 considered PFAS-treated carpets, PFAS-treated food contact materials, and cosmetics as examples of how a product's use is likely to lead to human exposure through ingestion and dermal absorption. Consumer products can also lead to releases to the environment when the product is washed off or laundered, entering sewers, treatment plants, and eventually waterways. The availability of suitable non-fluorinated alternatives makes the use of PFAS in many of these products unnecessary.

Case Study 5 looks at end-of-life impacts of PFAS-treated products. Waste incineration may destroy PFAS in products if 1000 °C operating temperatures are reached, but such temperatures are not typical of most incineration capacity (the EU's Industrial Emissions Directive, for example, requires a temperature of 850 °C). If landfilled, the PFAS will remain even after the product's core materials break down. The compounds will eventually migrate into liquids in the landfill, then into leachate collection systems or directly into the natural environment. They may then enter drinking water supplies, be taken up by edible plants and bioaccumulate in the food chain.

A number of other costs related to PFAS contamination include loss of property value, reputational damage to a polluting company (as in the case of the recent Miteni bankruptcy), and the costs incurred by public authorities in responding to affected communities – including public outreach, surveys of contamination, and remedial measures.

For future investigations of this nature, it would be useful to have more information concerning the sites where production of PFAS and/or where manufacturing of products involving PFAS is occurring – both current and legacy activities. National inventories of such sites, including where fluorinated AFFFs have been used, would help estimates of the numbers of affected populations, and the extent of contamination where remediation may be needed. Another suggestion is to include industries producing or using PFAS in the European Pollutant Release and Transfer Register, so that information on the location and amount of releases to air and to water is available.

National registries of products containing PFAS would help inform how PFAS are used and contribute to better characterisation of the major sources of exposure from products. Finally, more research is needed concerning what happens to PFAS discharged from wastewater treatment plants and during incineration of PFAS.

5. Estimates of costs of inaction linked to exposure to PFAS

5.1 Health-related costs of exposure to PFAS

This section presents findings for the health-related costs of PFAS exposure at three different levels – occupational (high) exposure, elevated (medium) exposure and background (low) exposure. The quantification was carried out for a selection of scenarios and health endpoints. Health-related costs that could not be quantified are reviewed qualitatively.

5.1.1 *Occupational (high) exposure scenario: PFAS production and manufacture of PFAS-containing products*

Individuals who are regularly exposed to PFAS through their occupation (e.g. workers in manufacturing plants producing PFAS or PFAS-treated products) may face greater risk of developing illnesses that affect their health and well-being. The desk research identified two studies that investigated elevated health risks due to PFAS exposure among workers in Europe. One study investigated serum concentrations of PFOA and liver enzymes from 56 workers in a fluorochemical production plant. The study found that PFOA serum concentration was associated with higher ALT, GGT and ALP enzymes and lower bilirubin.[309] Another 2001 study conducted by a staff epidemiologist from 3M reported that occupational exposure to PFOA and PFOS in chemical plants in Antwerp and another site in the United States was associated with an increased level of cholesterol and triglycerides.[310] However, the findings were more cautiously stated in the study published several years later.[311]

One of the most well-known studies of occupational exposure to PFAS was carried out under the C8 Health Project, which gathered data from workers from the Dupont Washington Works facility in West Virginia from 1952–2008. The sample of workers was known as the worker cohort while the C8 Health Project also gathered data from a community cohort. A multi-mortality study was conducted for this worker cohort, which

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[309] Costa G *et al.* (2009). Thirty years of medical surveillance in perfluorooctanoic acid production workers. Journal of Occupational and EnvironmentalMedicine 51:364–372.

[310] Olsen G W (2001). A longitudinal analysis of serum perfluorooctanesulfonate (PFOS) and perfluorooctanonate (PFOA) levels in relation to lipid and hepatic clinical chemistry test results from male employee participants of the 1994/95, 1997 and 2000 fluorochemical medical surveillance program. Final report Epidemiology.

[311] Olsen G W *et al.* (2003). Epidemiologic assessment of worker serum perfluorooctanesulfonate (PFOS) and perfluorooctanoate (PFOA) concentrations and medical surveillance examinations. Journal of Occupational and Environmental Medicine, 45(3), pp.260–270 and Lerner, S. (2018), 3M knew about the dangers of PFOA and PFOS decades ago, internal documents show, The Intercept, 31.07.2018.

had a target population of 6,026.[312] The study found evidence of a potential elevated risk of death from kidney cancer due to prior exposure to PFOA in the workplace.

Other sources suggest that occupational exposure to PFAS may have developmental toxicity. For example, a pregnant female worker who had direct contact with PFOA through her employment at the Dupont facility in West Virginia gave birth to a child with multiple birth defects. Soon afterwards, the company did not allow women of reproductive age to work directly with the chemical.[313] This endpoint, however, was not confirmed in the C8 Health Project in West Virginia.[314] Another study conducted among workers from a 3M plant in Decatur, Alabama did not find a relationship with pregnancy outcomes.[315] The small number of individuals in this category of pregnant workers may limit the detection of a statistical pattern between exposure to PFOA and pregnancy outcomes.

Overall, the evidence suggets that occupational exposure to PFAS may lead to an elevated risk of kidney cancer, a disease that can lead to significant costs in terms of health care expenditures, reduced quality of life, and premature death. The valuation for the health-related costs due to occupational exposure to PFAS focused on the kidney cancer endpoint for which there is epidemilogical evidence.

An assessment was made by drawing on the findings from the cohort mortality study of workers from West Virginia[316] extrapolated to the European context. Like other epidemiological studies carried out under the C8 Health Project, the cohort mortality study had a robust design and was overseen by a Science Panel of three epidemiologists. The sample for the study was restricted to individuals who had worked at least one day at the Dupont chemical plant in West Virginia between 1948 and 2002. The sample was divided into four groups based on their estimated level of exposure to PFOA. The study found that high occupational exposure to PFOA was associated with an increased risk of death due to kidney cancer.

As explained in the Chapter 4, it was not possible to develop a firm estimate of the number of plants that manufacture PFAS or products using PFAS in Nordic and EU countries. Some assumptions were made in order to generate estimates to support the valuation of the health-related costs for the study. The first assumption is that 20 manufacturing plants produce PFAS in European countries (see conclusion to Case Study 1 at page 64). The second assumption relies on Case Study 2's research that identified a total of 352,764 small (less than 250 employees) and 780 large manufacturers (more than 250 employees), which may use or emit PFAS, in EEA countries. As Case Study 2 explains, no information was available concerning which plants used PFAS in manufacturing their products nor how many workers were employed at each plant. In the absence of concrete

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[312] Steenland K and Woskie S (2012). Cohort mortality study of workers exposed to perfluorooctanoic acid. American journal of epidemiology. 176(10) pp.909–917.

[313] Mordock J, C8 suspected in birth defects: One woman's story, Delaware Online, April 2 2016. Accessed 12.10.2018.

[314] An overview of the probable link evaluations from the C8 Health Project can be found here

[315] Grice M *et al.* (2007). Self-reported medical conditions in perfluorooctanesulfonyl fluoride manufacturing workers. Journal of Occupational and Environmental Medicine 49:722–729.

[316] Steenland K and Woskie S (2012). Cohort mortality study of workers exposed to perfluorooctanoic acid. American journal of epidemiology. 176(10) pp.909–917.

information, the calculations assume that 3% to 10% of these plants use PFAS. As a last step, in order to generate the size of the exposed population, it was assumed that small plants had 30 workers on average while large plants had 300 workers on average. The population with occupational exposure in Europe was therefore estimated to range between 334,508 and 1,091,692 (see Annex 2 for more information).

The analysis assumed that these individuals suffered an elevated risk of mortality from kidney cancer as documented from the West Virginia study.[317] The number of additional deaths due to PFAS exposure in this population was then estimated to be between 3.6 and 11.8. These deaths were then monetised using the lower bound of the ECHA "value of a statistical life".

Table 20 presents a summary of the findings, which give an indication as to the potential scale of the health impacts for the scenario of occupational exposure to PFAS. A key uncertainty in constructing these estimates was the number and distribution of worker exposure to PFAS.

Table 20: Occupational exposure scenario: Monetised annual health impact for manufacturing worker exposure to PFAS

Findings	Annual estimates
Exposed population in Europe	335 thousand to 1.1 million
Population experiencing elevated health risk	83,627–273 thousand
Deaths due to kidney cancer linked to PFAS exposure	3.6 to 11.8 lives lost
Value of life lost	EUR 12.7 million–41.4 million

Note: For more information on this calculation please refer to Annex 2.

5.1.2 *Elevated (medium) exposure scenario*

The case studies identify two populations that are at risk for elevated exposure to PFAS. The first population are communities that are in close proximity to chemical plants that produce PFAS or PFAS-treated products (Case Studies 1 and 2). Contaminated water from these plants may enter the drinking water system serving the communities. The second population are communities that live close to sites contaminated by aqueous fire-fighting foams (Case Study 3). PFAS in the foam can seep into the ground and groundwater, leading to contamination of local drinking water supplies.

A Swedish study found that up to 300,000 of residents in the country – or about 3% of the total population – are or have been exposed to levels of PFAS above the action value, via municipal drinking water.[318] The study highlights two main sources for the contamination: close proximity to a plant producing PFAS or PFAS-treated products, and close proximity to areas with high utilisation of aqueous fire-fighting

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[317] Steenland K and Woskie S (2012). Cohort mortality study of workers exposed to perfluorooctanoic acid. American journal of epidemiology. 176(10) pp.909–917.

[318] Holmström *et al.* (2014). Nationell screening av perfluorerade föroreningar (PFAA) i dricksvatten. Rapport no 2014/20 (In Swedish). It should be noted that 1.4 million of Sweden's 9.9 million residents are not connected to a municipal water system. It is assumed nonetheless that all residents have contact with municipal waste water at least occasionally.

foams. These same individuals may also suffer higher exposure to PFAS due to contaminated surface water or air emissions.
The case studies provide other estimates for the number of individuals with elevated exposure. For example, Case Study 1 notes that 750,000 individuals living downstream from the Dordrecht Chemours plant had elevated exposure to PFAS via air and drinking water, and were advised to limit the consumption of vegetables grown in the area.[319] On the other hand, the affected population may be minimal if the surrounding vicinity has few inhabitants. For example, in the case of the 3M manufacturing plant in Antwerp, the PFAS contamination was considered to have concentrated on the area of the port where few people reside.

Elevated levels of PFAS in affected communities is highlighted in several studies (see Table 21). The blood serum concentration levels and the type of PFAS compounds, however, vary. Studies from the C8 Health Project in West Virginia found serum concentration levels of PFOA at 350 ng/ml among the nearby community.[320] The serum concentration level of PFOA in the general population in the United States was estimated to be 3.07 ng/ml in 2010.[321]

A study from a case of aqueous fire-fighting foam contamination in Sweden also found an elevated level of PFAS exposure among residents nearby.[322] Blood samples were taken from 3,660 persons, of whom 3,412 were in the contaminated area (Ronneby) and 242 people from a reference population in a nearby community (Karlshamn) that did not receive the contaminated water. Of the seven PFAS compounds identified in the contaminated water, three were identified at elevated levels in the blood serum of the sampled population and also elevated levels in the groundwater (above 90 ng/ml). The three main PFAS compounds identified in the blood serum were PFHxS, PFOA, and PFOS.

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[319] No Author, Another Chapter: Chemours releases GenX and PFOAs into waters globally, Encore, 08.08.2018. Accessed 10.10.2018.

[320] Frisbee S J *et al.* (2009). The C8 health project: design, methods, and participants. Environmental health perspectives, 117(12), 1873–82. DOI: https://doi.org/10.1289/ehp.0800379

[321] Center for Disease Control and Prevention (2018). Fourth National Report on Human Exposure to Environmental Chemicals. Updated Tables Volume1.

[322] Li Ying *et al.* (2017). Technical Report: Half-lives of PFOS, PFHxS and PFOA after end of exposure to contaminated drinking water.

Table 21: Review of serum concentration levels (ng/ml) in contaminated and outside contaminated areas – three examples

	Ronneby, Sweden (AFFF contamination)		West Virginia, USA (chemical plant)		Veneto Region, Italy[1] (chemical plant)	
	Outside contaminated area	Contaminated area	Outside contaminated area[2]	Contaminated area[3]	Outside contaminated area	Contaminated area
Sample size	242	3,418	2000+	32,254	250	257
Study year	2014–2016		2009–2014	2005–2006	2015–2016	
PFHxS	0.84	152	1.35	n.a.	n.a.	2.98
PFOA	1.59	10.4	3.07	32.9	0.01	13.77
PFOS	4.21	176	4.99	19.6	0.01	8.69

Source: 1) Ingelido A M *et al.* (2018). Biomonitoring of perfluorinated compounds in adults exposed to contaminated drinking water in the Veneto Region, Italy. Environment international, 110, pp.149-159.
2) Center for Disease Control and Prevention (2018). Fourth National Report on Human Exposure to Environmental Chemicals. Updated Tables Volume 1.
3) Frisbee S J *et al.* (2009). The C8 health project: design, methods, and participants. Environmental health perspectives, 117(12), 1873–82.

Epidemiological studies on the health impacts of elevated levels of exposure are available from West Virginia and the Veneto Region. One West Virginia study[323] found an increased risk of high cholesterol, while other studies found a higher risk of cancer (kidney and testicular) and hyperuricemia.[324] A study from the Veneto Region found that residents suffered an increased risk of overall mortality due to exposure to PFAS from a nearby manufacturing plant.[325]

The valuation for health-related costs for population of affected communities focused on the all-cause mortality endpoint using the increased risk factor found in the Veneto Region study.[326] The calculation relied on the 3% estimate from Sweden and assumed that the distribution of contaminated sites in Sweden is comparable to other European countries and that a similar share of the population is exposed at medium levels. In reality this is likely to be a low estimate – the prevalence of elevated exposure may be higher in countries with more manufacturers of PFAS-treated products and countries with higher population density. The assumption of 3% is however bolstered by findings from the United States where national drinking water monitoring data suggests that a higher share of the population (about 4.5%) is exposed to elevated levels of PFAS.[327]

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[323] Steenland K *et al.* (2009). Association of perfluorooctanoic acid and perfluorooctane sulfonate with serum lipids among adults living near a chemical plant. American journal of epidemiology, 170(10), pp.1268–1278.

[324] Steenland K *et al.* (2010). Association of perfluorooctanoic acid (PFOA) and perfluorooctane sulfonate (PFOS) with uric acid among adults with elevated community exposure to PFOA. Environmental health perspectives, 118(2). p.229. and Barry V *et al.* (2013). Perfluorooctanoic acid (PFOA) exposures and incident cancers among adults living near a chemical plant. Environmental health perspectives, 121(11–12), p.1313.

[325] Mastrantonio M *et al.* (2017). Drinking water contamination from perfluoroalkyl substances (PFAS): an ecological mortality study in the Veneto Region, Italy. The European Journal of Public Health. Feb 1;28(1):180–185.

[326] Ibid.

[327] The Groundwater Association (2017). PFAS Top 10 Facts.

The calculation then assumes that the exposed adult population would face an elevated risk of mortality on the order of magnitude found in the Veneto region study. Using the baseline death rate reported by Eurostat[328], the calculation suggests that more than 12,000 deaths annually could be attributed to elevated PFAS exposure in the EU with an estimated loss of EUR 43 billion. A similar calculation for only the Nordic countries[329] suggests that almost 600 deaths annually are linked to PFAS, with a total value of EUR 2 billion.

Table 22 presents a summary of the calculations, which indicate the potential scale of the health-related costs of elevated (medium) PFAS exposure in adults living in affected communities.

Table 22: Monetised annual costs due to elevated risk of all-cause mortality for adults living close to PFAS contamination

	Nordic countries	EEA countries
"Exposed" population (3%)	621 thousand	12.5 million
Annual deaths linked to PFAS	587–692	11,745–13,843
Valuation of life lost	EUR 2.1–2.4 billion	EUR 41.1–48.5 billion

Note: For more information on this calculation please refer to Annex 2.

Pregnancy outcomes may also be affected in communities with elevated exposure. As seen in Table 23 low birth weight (weight less than 2,500 grams) is a health endpoint pointed out in several studies. The EFSA report notes that *there is an overall tendency towards an inverse correlation between concentrations of PFOS/PFOA and birth weight*[330] whereas the five-year retrospective study conducted as part of the C8 Health Study in West Virginia[331] found that PFOS, but not PFOA, to be associated with low birthweight.

The prevalence of low birth weight in Europe is estimated to be 6.8%.[332] Assuming that 3% of births take place in areas with elevated (medium) levels of exposure to PFAS, an estimated 3,544 births in EEA countries are low birth weight due to exposure to PFAS. In the Nordic countries, the prevalence of low birth weight is less (4.57%); in applying the same relative risk function, the analysis suggests that 271 births each year in Nordic countries are low birthweight due to medium level PFAS exposure.

Low birth weight may be associated with a higher risk of developing diseases in adulthood such as cardiovascular disease, respiratory disease and diabetes.[333] Low birthweight

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[328] Eurostat provides the rate of deaths per 100,000 for Europe. For the Nordic Countries, a weighted average was used.

[329] Aside from the smaller population/exposed population, the key difference is the lower death rate for the Nordic countries, compared to the overall EU death rate.

[330] EFSA CONTAM Panel (EFSA Panel on Contaminants in the Food Chain), Knutsen HK *et al.*, 2018. Scientific opinion on the risk to human health related to the presence of perfluorooctane sulfonic acid and perfluorooctanoic acid in food. EFSA Journal 2018;16(12):5194, 128 pp. DOI: https://doi.org/10.2903/j.efsa.2018.5194

331 Stein C R *et al.* (2009). Serum levels of perfluorooctanoic acid and perfluorooctane sulfonate and pregnancy outcome. American journal of epidemiology, 170(7), pp.837–846.

[332] OECD, 2016. Health status statistics.

[333] Almond D and Currie J (2011). Killing me softly: The fetal origins hypothesis. Journal of economic perspectives, 25(3), 153–72. And Bharadwaj P *et al.* (2017). Birth Weight in the Long Run. Journal of Human Resources, 53(1), 189–231.

is also associated with other important outcomes such as impaired cognitive development. For example, one study found that low birth weight was associated with a 25% lower likelihood of passing high school exit exams and a higher risk of unemployment at age 33 years.[334] Other studies have found that birth weight is positively associated with earnings.[335] For example, one study found that low birth weight was associated with lower income for men 30 years of age and for women between 50 and 60 years of age.[336] The researchers found that part of this effect could be explained by a higher use of sick leave, which suggests a higher susceptibility to illness. This increased risk of illness could be relevant for 271 low birth weight persons born each year in the Nordic countries and for the estimated 3,544 low birth weight persons born each year in EEA countries.

Table 23: Number of births per year that are low birth weight in areas close to PFAS contamination

	Nordic countries	EEA countries
Births in "exposed" areas	8,843 births	156,344 births
Births of low birth weight linked with PFAS	271 births	3,544 births

Note: For more information on this calculation please refer to Annex 2.

5.1.3 *Background (low) exposure scenario*

PFAS are widely present in consumer goods as highlighted in Case Study 3 (see Section 3.3). Consumer goods can contribute to human exposure to PFAS through several pathways. First, it can enter humans through direct hand-to-mouth transfer through products such as food contact materials. Second, PFAS-treated consumer goods like cosmetic products may end up in wastewater that then affects the water supply.

Some research suggests that children have an elevated exposure to PFAS and that this is due to frequent hand-to-mouth transfer and proximity to dust on the floor.[337, 338] Young children may also have greater exposure to PFAS-treated carpets.[339] While this conclusion of greater exposure for children is not supported by population-level bio-

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[334] Currie J and Hyson R (1999). Is the impact of health shocks cushioned by socioeconomic status? The case of low birthweight. American Economic Review, 89(2), 245–250.

[335] Black S *et al.* (2007). From the cradle to the labor market? The effect of birth weight on adult outcomes. The Quarterly Journal of Economics, 122(1), 409–439 and Bharadwaj P *et al.* (2017). Birth Weight in the Long Run. Journal of Human Resources, 53(1), 189–231.

[336] Bharadwaj P *et al.* (2017). Birth Weight in the Long Run. Journal of Human Resources, 53(1), 189–231.Table F.

[337] Winkens K *et al.* (2017). Early life exposure to per- and polyfluoroalkyl substances (PFASs): A critical review. Emerging Contaminants. 3: 55–68. DOI: https://doi.org/10.1016/j.emcon.2017.05.001

[338] Rappazzo K *et al.* (2017). Exposure to perfluorinated alkyl substances and health outcomes in children: a systematic review of the epidemiologic literature. International journal of environmental research and public health, 14(7). p. 691. Jun 27;14(7). pii: E691. DOI: https://doi.org/10.3390/ijerph14070691

[339] Trudel, D., Horowitz, L., Wormuth, M., Scheringer, M., Cousins, I. T., & Hungerbühler, K. (2008). Estimating consumer exposure to PFOS and PFOA. Risk Analysis: An International Journal, 28(2), 251-269.

monitoring data from the United States for three PFAS compounds (see Table 24) nevertheless a low level exposure to chemicals at critical periods of development such as infancy and childhood may have serious, irreversible impacts.[340]

Table 24: Serum concentration levels by age level (USA, 2013–2014)

	PFNA	PFOA	PFOS	Sample size
3–5 years	0.764	2.00	3.38	181
6–11 years	0.809	1.89	4.15	458
12–19 years	0.599	1.66	3.54	401
20 years and older	0.685	1.98	5.22	1,764

Source: CDC, 2018. Fourth National Report on Human Exposure to Environmental Chemicals. Updated tables, Volume 1.

A review of studies on the health impacts of exposure to PFAS among children identifies four key health endpoints[341], namely high cholesterol, depressed immunity (including lower vaccine response and higher risk of asthma), reduced renal function, and younger age at menarche. These endpoints are reflected in the overall review of endpoints presented in Table 25.

It is challenging to monetise the increased risk of these health endpoints among children. It requires a life course view and a clear understanding of the complex relationships between the endpoints, other factors and the consequent impacts on development and well-being. For example, reduced renal function among children is associated with having delayed motor skills and language development, and trouble with concentration and self-esteem. Such issues could have cost implications in terms of more doctor visits, as well as poorer educational achievement. Among the four conditions mentioned above, depressed immunity was found to be the most amenable to quantification. As stated in Rappazzo *et al.*, 2017, *the studies of vaccine response were well done cohort study designs and despite the small number offer compelling evidence. The asthma studies are less consistent and include a broader range of study designs and quality.*[342]

Several regulatory bodies highlight immunotoxicity as a likely health consequence of PFAS exposure (e.g. EFSA, ATSDR and US-EPA). However, a closer review of the evidence for specific endpoints presents a more mixed picture. For example, the US-EPA validation studies conclude that the relationship between prenatal and maternal exposure to PFOA and PFOS and infectious disease is limited. While some studies identified a relationship with common childhood infections such as otitis media, allergies, common colds and the flu, the evidence was not consistent. For example, the C8

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[340] As stated in Rappazzo *et al.* (2017): *It is increasingly understood that exposure to environmental chemicals during sensitive windows has the potential to permanently alter a child's risk of future morbidity, even at doses that have little effect in adults.*

[341] Rappazzo K *et al.* (2017). Exposure to perfluorinated alkyl substances and health outcomes in children: a systematic review of the epidemiologic literature. International journal of environmental research and public health, 14(7). p.691. Jun 27;14(7). pii: E691.

[342] Ibid.

Science Panel concluded that there is no probable link between PFOA and common infections.[343] If greater susceptibility to illness is indeed a health endpoint, PFAS exposure may then be linked to costs related to more doctor's visits, fewer days attending school and lower workplace engagement for caretakers. Increased sickness among children may be due to a wide range of factors other than PFAS exposure and thus it would be important to base any estimation on studies with a robust design.

A Danish study explored the potential scale of the immunotoxicity endpoint. The study found that higher prenatal exposure to PFOS was associated with more days of fever among children ages 1 to 4 years.[344] For this study a calculation was made assuming that the level of PFAS exposure and the level of risk of fever could be directly extrapolated to the Nordic and the EEA countries. The estimated number of days of fever that may be attributable to PFAS exposure are presented below.

Table 25: Additional fever days among children ages 1–4 years due to PFAS exposure

	Nordic countries	EEA countries
"Exposed" children	45,229	784,794
Fever days in exposed population – overall	212,576	3,688,533
Fever days in exposed population – linked to PFAS exposure	83,742	1,453,059

Note: For more information on this calculation please refer to Annex 2.

5.1.4 Background exposure (low) scenario

Discharges of PFAS from waste water treatment plants and landfills may lead to contamination of food and water, which are the two main sources of exposure to PFAS.[345] Case Study 5 (section 3.5) notes that PFAS released from products in landfills can migrate directly into soil and groundwater. The discharge may include a high level of long-chain PFAS compounds such as PFOA even if their production has been restricted in recent years. Contaminated water can travel long distances and be taken up in agricultural produce and drinking water, potentially affecting all persons in Europe. Lastly, evidence suggests that wastewater treatment is not effective at fully removing PFAS within the general population.

This study assessment found that exposure to PFAS through the pathway of waste water treatment plants and landfills may be most closely linked to background levels of PFAS in drinking water and food. Other factors may contribute to background levels of PFAS, for example, the disposal of consumer goods and exposure to dust.

The blood serum concentration of European populations with background levels of exposure to PFAS is not well-known. Some biomonitoring studies have been conducted

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[343] Environment Protection Agency (2016). Health effects support document for perfluorooctanoic acid (PFOA). Document no: EPA822R16003 and Health effects support document for perfluorooctane sulphate (PFOS). Document No: EPA822R16002.

[344] Dalsager L *et al.* (2016). Association between prenatal exposure to perfluorinated compounds and symptoms of infections at age 1–4years among 359 children in the Odense Child Cohort. Environment international, 96, pp.58–64.

[345] Trudel D *et al.* (2008). Estimating Consumer Exposure to PFOS and PFOA. Risk Analysis: An International Journal 28.2: 251–269.

among small populations as shown in Table 26. While the generalisability of these findings is limited due to the small sample sizes, the findings nevertheless provide insight into the levels of background PFAS exposure in different contexts.

Table 26: Cross-country estimates of background PFAS levels in blood serum of adult populations

	Italy[1]	Norway[2]	Sweden[3]	Belgium[4]	Spain[5]	Germany[6]	Greece[7]	USA[8]
Year	2015–2016	2006	1997–2000	1998, 2000	2006	2005	2008	2009–2014
Sample size	257	57	66	20	48	356	86	2,000+
PFOA	1.64	2.7	5.0	4.1	3.4	13.7	2.05 (male) 1.92 (female)	3.07
PFNA	0.58	0.55	--	--	--	--		0.675
PFDA	0.32	0.22	--	--	--	--		0.185
PFUnDA	0.18	0.14	--	--	--	--		--
PFDoDA	0.04	--	--	--	--	--		--
PFHxS	2.49	1.4	3.0	1.3	5.8	--		1.35
PFOS	5.84	12	34.2	17.2	15.2	5.7	13.63 (male) 9.28 (female)	4.99

Source: 1) Ingelido A M *et al.* (2018). Biomonitoring of perfluorinated compounds in adults exposed to contaminated drinking water in the Veneto Region, Italy. Environment international, 110, pp.149–159.
2) Haug L S *et al.* (2009). Time Trends and the Influence of Age and Gender on Serum Concentrations of Perfluorinated Compounds in Archived Human Samples. Environ. Sci. Technol. 43:6, 2131–2136.
3) Kärrman A *et al.* (2004). Levels of perfluoroalkylated compounds in whole blood from Sweden. Organohalogen Compd. 66, 4008–4012.
4) Kannan K *et al.* (2004). Perfluorooctanesulfonate and related fluorochemicals in human blood from several countries. Environ. Sci. Technol. 38, 4489–4495.
5) Ericson I *et al.* (2007). Perfluorinated chemicals in blood of residents in Catalonia (Spain) in relation to age and gender: a pilot study. Environ. Int. 33, 616–623.
6) Holzer J *et al.* (2008). Biomonitoring of perfluorinated compounds in children and adults exposed to perfluorooctanoate (PFOA) contaminated drinking water. Environ. Health Perspect. 116, 651–657.
7) Holzer J *et al.* (2008). Biomonitoring of perfluorinated compounds in children and adults exposed to perfluorooctanoate (PFOA) contaminated drinking water. Environ. Health Perspect. 116, 651–657.
8) Center for Disease Control and Prevention (2018). Fourth National Report on Human Exposure to Environmental Chemicals. Updated Tables Volume 1.

In contrast to these small-scale biomonitoring studies, a large, nationally-representative population-based survey that includes biomonitoring is conducted every two years in the United States. The survey is known as the National Health and Nutrition Examination Survey (NHANES). One of the survey modules involves a health examination and the collection of a blood sample. The blood samples are analysed for a wide range of chemicals including PFAS. One analysis concluded that the levels of

PFOS, PFOA and PFHxS in blood serum in the United States were comparable to several European countries.[346] This conclusion supports the transferability of findings from studies conducted in the United States on the health impacts of background exposure to PFAS to the European context.

Several analyses using the NHANES data suggest that PFAS exposure at background levels can increase the likelihood of cardiovascular disease. One study found a positive correlation with uric acid[347] while another found an association with total cholesterol[348], which are both risk factors for cardiovascular disease. Another study found an association between PFOA and risk of developing hypertension.[349] The level of consensus was found to be highest for serum cholesterol. The epidemiological evidence relating elevated cholesterol and cardiovascular disease, however, is quite mixed. Another complicating factor is that studies investigating PFAS exposure do not assess the relative risk of cholesterol over the acceptable thresholds. Rather, they provide estimates for the elevation of cholesterol, which may remain below the acceptable threshold.

Due to challenges related to the serum cholesterol endpoint, the quantitative assessment focused on hypertension. The risk relationship between PFAS and hypertension was based on findings from a study from the United States (see Table 27).[350] Individuals with a systolic blood pressure greater than 140 mm Hg, a diastolic blood pressure greater than 90 mm Hg or a self-reported medical diagnosis were considered to have hypertension.

Table 27: Risk of developing hypertension as a function of exposure to PFOA contamination

Serum PFOA concentration	Odds-ratios (95% confidence interval)
Quartile 1 (<2.6 ng/ml)	1 (Reference)
Quartile 2 (2.7–3.9 ng/ml)	1.24 (0.89–1.74)
Quartile 3 (4.0–5.5 ng/ml)	1.63 (1.20–2.20)
Quartile 4 (>5.6 ng/ml)	1.60 (1.15–2.22)

Note: The analysis of hypertension is based on a sample of 2,208 adults (20 years and older) who provided a blood sample between 2003 and 2006 to the National Health and Nutrition Examination Survey.

Source: Min *et al.*, 2012.

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[346] Kato K *et al.* (2011). Trends in exposure to polyfluoroalkyl chemicals in the US population: 1999– 2008. Environmental science & technology, 45(19), pp.8037–8045.

[347] Shankar A *et al.* (2012). Perfluorooctanoic acid and cardiovascular disease in US adults. Archives of Internal Medicine, 172(18), pp.1397–1403.

[348] Nelson J *et al.* (2010). Exposure to polyfluoroalkyl chemicals and cholesterol, body weight, and insulin resistance in the general US population. Environmental health perspectives, 118(2), 197.

[349] Min J Y *et al.* (2012). Perfluorooctanoic acid exposure is associated with elevated homocysteine and hypertension in US adults. Occup Environ Med, 69(9):658–62.

[350] Ibid.

The analysis assumes that the entire adult population in Europe is exposed to background level exposure of PFOA through drinking water, and that about half have a level of exposure that is associated with a higher risk of developing hypertension. The latter assumption follows from a finding from the US study, where the risk for developing hypertension was elevated for individuals in the highest two quartiles of exposure. Several additional assumptions were made. For example, an estimated 6.1 million new cases of cardiovascular disease were diagnosed in the EU in 2015[351], of which about half were assumed to be specifically related to hypertension.[352] The assessment then considered the increased risk of mortality due to hypertension.[353] These assumptions are presented in greater detail in Annex 2 and the findings are presented in Table 28. The analysis finds an estimated 12,655 to 41,417 cases of hypertension linked to PFAS exposure in the Nordic countries and about 153 to 500 deaths linked to hypertension and PFAS exposure. The estimated number of deaths that could be attributed to PFAS exposure in the EEA countries ranged from 3,066 to 10,035. Key uncertainties in developing these estimates is the underlying risk relationship between PFAS exposure and hypertension and the elevated risk of mortality associated with hypertension.

Table 28: Monetised health impact (EUR) for background PFAS exposure leading to increased risk of developing hypertension

	Nordic countries	EEA countries
Population at elevated risk of hypertension	10.3 million	207.8 million
Cases of hypertension linked to PFAS	12,655–41,417	254,167–831,818
Deaths linked to hypertension and PFAS	153–500	3,066–10,035
Valuation of life lost	EUR 687 million–2.2 billion	EUR 10.7 billion–35 billion

Note: For more information on this calculation please refer to Annex 2.

These figures do not capture all the costs associated with hypertension. Hypertension can also lead to other costs including health care costs, productivity lost and the cost of uncompensated care.[354] Moreover, in general, these figures do not include utility costs, i.e. the benefits of being fit and well and enjoying life to the fullest.

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[351] European Heart Network (2017). European Cardiovascular Disease Statistics 2017.

[352] In the same report it is stated that high systolic blood pressure contributes for about half of all cardiovascular diseases.

[353] Zhou *et al.* (2018). Uncontrolled hypertension increases risk of all-cause and cardiovascular disease mortality in US adults: the NHANES III Linked Mortality Study. Scientific reports, 8(1), p.9418.

[354] European Heart Network (2017). European Cardiovascular Disease Statistics 2017.An estimated 53 percent of the cost of cardiovascular disease (which includes hypertension) in the EU is accounted for by health care costs (EUR 111 billion), while 26 percent is due to productivity loss (EUR 54 billion) and the remainder is due to the provision of uncompensated care (EUR 45 billion). CVD can account for about 19 percent of all DALYs lost in the EU annually.

5.1.5 *Summary of health-related costs of exposure to PFAS*

Table 29 presents an overview of the preliminary quantitative assessments of the health-related costs from PFAS exposure by the source.

Table 29: Health-related costs (of exposure to PFAS)

Exposure level	"Exposed" population and source	Health endpoint	Nordic countries		All EEA countries	
			Population at risk	**Annual costs**	**Population at risk**	**Annual costs**
Occupational (high)	Workers at chemical production plants or manufacturing sites	Kidney cancer	n.a.	n.a.	84–273,000	EUR 12.7–41.4 million
Elevated (medium)	Communities near chemical plants, etc. with PFAS in drinking water	All-cause mortality	621,000	EUR 2.1–2.4 billion	12.5 million	EUR 41–49 billion
		Low birth weight	8,843 births	136 births of low weight	156,344 births	3,354 births of low weight
		Infection	45,000 children	84,000 additional days of fever	785,000 children	1,500,000n additional days of fever
Background (low)	Adults in general population (exposed via consumer products, background levels)	Hyperten-sion	10.3 million	EUR 0.7–2.2 billion	207.8 million	EUR 10.7–35 billion
Totals			*Nordic countries*	*EUR 2.8–4.6 billion*	*All EEA countries*	*EUR 52–84 billion*

5.2 Non-health costs of environmental contamination with PFAS

Environment-related costs are considered here to cover the following elements:

1. Monitoring to assess PFAS contamination where it is suspected.
2. Provision of a temporary uncontaminated drinking water supply.
3. Upgrading of water treatment works and ongoing costs for maintenance and replacement and disposal of filters.
4. Excavation and treatment of soils.
5. Health assessments where contamination is found (health management costs, rather than costs of damage to health).
6. Impacts on biodiversity.

Data collected during the study on elements 1 to 5 of this list are provided in Annex 3, Part 1, with summary estimates provided in this Section. The Annex also includes information on the Purchasing Power Parity (PPP)-adjusted exchange rates used and factors applied to account for inflation.

5.2.1 Impacts on, and public aversion to, risks to the natural environment

Direct assessment of impacts on biodiversity is not possible, given a lack of data on the stock at risk, exposure-response, and other elements of the analysis. However, it is noted that various ecological impacts may be associated with the release of PFAS, ranging from impacts to the endocrine and immune systems of animals to restrictions on human fishing activity (e.g in the cases of the contamination at Schiphol Airport and at Arnsberg in Germany, referred to above). For contamination of the River Rhine from Dusseldorf Airport, affected usages have been listed as being associated with the water works, local water rights including private wells, anglers, surfing club, and agricultural uses.[355]

For specific cases it may be possible to value elements such as lost fishing opportunity. Valuation data were generated for a specific case in the USA by Sunding as noted above, but this requires information on levels of fishing activity, the extent to which recommendations not to consume locally caught fish affects angling activity, the duration of any such recommendation, etc. and is beyond the scope of a generic study such as this. It is, however, important to note that Sunding's estimate based on willingness to pay to avoid fishing in PFOS contaminated surface waters for the one case of contamination arising from 3M's disposal of PFCs in Washington County, Minnesota amounted to the equivalent of over EUR 90 million for the period 2008–2040. This supports the view that loss of amenity associated with contamination of fish purely from the perspective of anglers is substantial.

Section 3.2.3 reported on a UK study undertaken to inform the development of the REACH Restriction on D4 and D5 in wash-off personal care products. This found a willingness to pay of EUR 46 per year per person to reduce the risks associated with the PBT substance – D4, and EUR 40 per year per person to reduce the risks associated with the vPvB substance – D5. The results of the survey could be used to provide an estimate of the total willingness to pay to avoid contamination with PBT/vPvB substances including PFAS. Such a result could be useful in the context of evaluation of a REACH Restriction or Authorisation where the costs of alternatives are substantially less (e.g. an order of magnitude) than the WTP estimate, or where the WTP for specific beneficial properties associated with the substance under investigation are also provided for comparison (as was the case with the D4/D5 Restriction).

For the purpose of the present study it seems better not to include the figures given the uncertainties that are associated with them, but to acknowledge firstly that economic estimates exclude ecological damage, and secondly that the costs linked to aversion to PBT and vPvB substances are likely to be substantial. The results of the UK study applied at a European scale suggest this aversion has an economic cost running into the billions of Euro.

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[355] Weber R (2016). Some lessons learned from PFOS/PFAS management in Germany.

5.2.2 Summary of the non-health unit costs associated with environmental contamination with PFAS

Data from Annex 3, Part 1 on the non-health costs associated with environmental contamination with PFAS have been reviewed and collated to provide best estimates and associated ranges, see Table 30. The logic for defining best estimates and ranges is discussed below. Where possible, estimates are provided as cost per person to enable aggregation at a later stage.

About half of the data that has been collected comes from the USA, raising questions about its transferability to Europe. Inspection of the data suggests that there is broadly as much variation within the European and US data sets, so both are included. Comparison of the US and European data could be taken to indicate that attitudes to risk aversion in the two regions are broadly similar (acknowledging the high level of variation in both the European and US datasets).

An important factor constraining the ranges (even though many are broad) is the fact that when scaling up from information collected in the case studies, the analysis needs to adopt representative best estimates and associated ranges around those best estimates. The costs of individual schemes may well lie outside these ranges, but the analysis needs to deal with average costs, not the extremes from specific cases which by their nature would lead to an over-or under-estimation of costs.

Table 30: Summary of cost data for non-health expenditures. For units, see second column

Activity	Unit	Best estimate	Range from studies	Adopted range
Monitoring	Cost/sample	EUR 340	EUR 278–402	EUR 278–402
	Cost/case	EUR 50,000	EUR 4.0 thousands –6.1 million	EUR 25 thousands –500 thousands
Health assessment (including biomonitoring)	Cost/person	EUR 50	No range	EUR 5–95 (+/-90%)
	Total biomonitoring and health assessment per case where it is considered appropriate	EUR 3.41 million	EUR 2.5 million – 4.3 million	EUR 1 million –5 million
Provision of temporary uncontaminated supply	Cost/person	No relevant data: Hoosick Falls information rejected as it does not appear to be for a true "temporary" solution (see text)		
Provision of a new pipeline	Cost/person	EUR 800	EUR 37–5,000	EUR 500–1,500
Upgrading water treatment works (capital)	Cost/person	EUR 300	EUR 8–2,200	EUR 18–600
Upgrading water treatment works (maintenance)	Cost/person	EUR 19	EUR 8–30	EUR 8–26
Excavation and treatment of soils	Cost/kg PFAS	EUR 280,000	EUR 100 thousands –4.3 million	EUR 100 thousands –1 million
	Cost/case	EUR 5 million	EUR 100 thousands –3 billion	EUR 300 thousands –50 million

With respect to monitoring, costs per sample concern the collection of individual samples of groundwater (etc.) and the analysis of those samples. Associated costs do not account for additional monitoring related activities, such as management of the monitoring regime. The reported costs per sample for monitoring were from a single study, but provided with a range indicating economies of scale as more monitoring was done. Relative to other parameters the range for monitoring is narrow, and the mid-point is adopted as the best estimate. A more important question for the analysis concerns how much monitoring would need to be carried out in total and in any country and with what frequency. This could vary from none or a few samples to several thousand. Figures expressed as average monitoring cost per case could therefore be more reliable. The range here is much larger, reflecting differences in the degree of contamination, and the extent of the population affected. Issues relating to the data will concern the activities included under "monitoring": in some cases these will cover only sampling and analysis, whilst in others they may include development of plans for public protection as well.

Two sources of information concerning the costs of carrying out health assessments are considered[356], WHO's evaluation of a health assessment scheme around the Veneto site of contamination, and biomonitoring costs incurred around Ronneby Airport in Sweden. Costs in both cases run into the millions of EUR. It is unknown how representative these cases are, but it is possible (given that this cost category has not been identified for other cases) that they are higher than similar costs incurred elsewhere if indeed such activities have been undertaken. For the Ronneby case there is no information on the scale of the biomonitoring undertaken, whereas WHO provide data on the number of individuals potentially affected in Veneto. Accordingly, the health assessment costs are taken from the Veneto case and cover surveillance of the population once significant exceedance has been observed. The Ronneby data are useful for indicating that where health assessment of some kind is considered appropriate, costs can run into millions of EUR.

The best estimate is equal to the figure derived from the Veneto data (in this case, the number of people factored into the calculation of the average cost per person was the total exposed population, not the number of individuals undergoing testing of any kind). The extent of health assessment could vary significantly, theoretically from none at all to detailed and regular assessment of all exposed individuals. This variation could reflect national attitudes to pollution, public concern over a particular incident, the extent of exceedance of limit values, etc. A range of +/-90% is adopted in the costs analysis, reflecting possible variability.

Two cases were identified for the costs of providing a temporary uncontaminated supply, from Hoosick Falls, New York State and Peterson, Colorado, both in the USA. Hoosick Falls was home to the Saint-Gobain Performance Plastics and Honeywell Manufacturing Plant, whilst Peterson contains a US Air Force Base. For Hoosick Falls a 'temporary filtration system' was installed. Associated costs also include investigation of alternative water sources. The Hoosick Falls estimate of EUR 7.4 million for provision of a temporary water filtration system is of a similar magnitude to the costs reported elsewhere for a permanent system. This suggests that the responsible authorities are seeking an alternative source with no contamination but that this will take several years to

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[356] The health assessment costs are considered in this section, rather than Section 5.1 as they relate to management of problems of PFAS contamination rather than health impacts.

come online. In the meantime they have introduced a system that is similar to the permanent solutions elsewhere. Bottled water has been supplied to residents in both areas. A cost of EUR 81,000 equivalent is cited for Peterson, but no cost data for bottled water have been identified for Hoosick Falls.
Considering estimation of the costs of provision of temporary clean water supplies elsewhere, it is noted that costs will vary substantially according to the following factors:

- the number of people served by a scheme;
- the duration over which alternative supplies are required; and
- the form of the temporary measures that are put in place (e.g. additional filtration, provision of bottled water, provision of water tankers, temporary piping).

On the basis that PFAS contamination will not be resolved quickly, the duration over which alternative supplies are required seems likely to be in the order of months or years rather than days or weeks. This in turn starts to rule out very prolonged use of some of the quick fixes such as provision of bottled or tanked water.

Four of the incidents for which cost data were obtained provide estimates indicating the costs of providing permanent new pipelines, these being the cases for Jersey, Kallinge, Stadtwerke Rastatt and Veneto. There are two orders of magnitude difference in the reported costs which show a strong dependence on the number of people presumed to be affected. Factors affecting costs include:

- whether a new connection is made to a single point that goes on to serve a larger area, as assumed for Rastatt, or to individual buildings as was the case for Jersey;
- the number of people affected;
- the distance over which new pipework is required; and
- complications in laying pipes associated with geology and local infrastructure

The costs in Jersey are significantly higher than the other two locations, reflecting the small number of houses affected and the need to connect to individual homes rather than a single point. The likely range for an average cost per person is taken from the lower bound to the upper bound of costs excluding Jersey (EUR 100–EUR 1,500/person) with the best estimate taken as the mid-point of this range (EUR 800).

For upgrading of water treatment plant the cost range is again broad, EUR 8 to EUR 2,200 when normalised against population (the "high" estimate is notably the supposed cost of the temporary solution at Hoosick Falls). Excluding the two highest and lowest values gives a reduced range of EUR 18 to EUR 940/person, with remaining values spread rather evenly over this range. Taking the mean of the 9 data points excluding the highest and lowest gives a best estimate of EUR 300/person.

For maintenance costs, there are four estimates for which normalisation against population has been performed, from EUR 8/person/year to EUR 30/person/year. The range is adopted from these studies and the best estimate (EUR 19) is taken as the midpoint.

For excavation of soils the range is again broad, with costs per kg of PFAS of EUR 100,000, EUR 200,000–280,000 and EUR 4.3 million. It is unclear whether all of these costs can be attributed to PFAS or to other contaminants.

Soil remediation costs can also be expressed on a per case basis. The range is again very broad, EUR 100,000 to EUR 3 billion, the very high upper bound referring to possible costs at Rastatt in Germany.[357] Adopting any value within this range is prone to very high uncertainty, though for the purpose of illustration, a best estimate of EUR 5 million/case is taken, with a range for the main cost of EUR 300,000 to EUR 50 million. Definition of the upper bound cost for soil remediation is extremely difficult, given the extreme variability in the cost data identified (see Annex 3). Most cases identified had costs ranging from EUR 1 million to EUR 10 million, but there are several that are substantially higher (Schiphol at EUR30–40 million, Dusseldorf Airport where costs are estimated at up to EUR 100 million, and Baden-Wurttemberg where costs are estimated between EUR 1 and 3 billion).

A number of other costs have also been identified for individual case studies, such as lost opportunity from closure of a borehole (Buncefield, UK), fees and capital works at specific sites not specifically involved in water treatment (Jersey) and risk analysis and project management (Uppsala). In each case, the total costs under this "other" category are substantial, covering a range of EUR 320,000 to EUR 6.3 million. Whilst no attempt is made to extrapolate these figures, given that they are only mentioned for single locations, they provide further evidence that the costs associated with remediation of PFAS contamination are large.

5.2.3 Aggregating the costs of environmental contamination with PFAS

A first step in aggregation is to simply combine the results for each European country as provided in Annex 3 part 1 (see Table 31 below). The results given do not represent an estimate of total damage for any country, as such a total has not been estimated for any country. The country for which data appear most complete is Sweden, where significant contamination has been found at 20% (7) out of the country's 35 airports (military and civilian combined). This figure of 20% is carried forward to the analysis that follows. The country for which highest costs are estimated is Germany, where the total is almost entirely due to soil remediation in Baden-Wurttemberg, which is understood to follow the use of waste material as a soil treatment on agricultural land.[358] It is further understood that the remediation of the soils in question has not been performed, so the cost estimate must be considered theoretical. The results demonstrate a variation in the estimated costs by around 2 orders of magnitude.

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[357] http://greensciencepolicy.org/wp-content/uploads/2016/09/Rolland-Weber-PFOS-PFAS-German-activities-Final.pdf

[358] Reuning A, Landschaft mit Gift, Deutschland Funk, 23.04.2017. Accessed 10.11.2018.

Table 31: Summation of the costs identified in the available literature, EUR millions by country. Figures in brackets indicate the number of cases or plant for which data were collected

Total costs	DK	DE	IT	NL	NO	SE	UK
Monitoring		EUR 7.8 (2)			EUR 0.50 (2)	EUR 2.6 (7)	
Upgrading treatment works		EUR 104 (2)	EUR 2.1 (1)			EUR 5.3 (5)	
Install new pipelines		EUR 1.81 (1)				EUR 11 (2)	EUR 1.0 (1)
20 year maintenance cost of water treatment works discounted at 4%		EUR 11 (1)				EUR 1.6 (1)	EUR 13 (1)
Soil remediation costs	EUR 15	EUR 3,112 (2)		EUR 35 (1)	EUR 4.1 (1)	EUR 2.5 (3)	EUR 7.1 (1)
Biomonitoring						EUR 2.6 (1)	
Other quantified costs						EUR 0.38 (1)	EUR 12 (2)
Total quantified cost	EUR 15	EUR 3,236	EUR 2.1	EUR 35	EUR 4.6	EUR 26	EUR 33
Sites affected	Copenhagen (AP)	Dusseldorf (fire), Rastatt (waste)	Veneto industry	Schiphol (AP)	Oslo Fjord, Tyrifjorden	Arlanda, Bromma, Kallinger, Kiruna, Ronneby, Umea, Uppsaala (all APs)	Buncefield (fire), Jersey (AP)

The results shown in Table 31 are incomplete because they omit most European countries and are based on limited knowledge of contamination across the continent. As such they describe the absolute minimum for addressing the PFAS problem to the extent that they have been incurred (noting the discussion above concerning the Baden-Wurttemberg case where soil remediation is still to take place). As a minimum estimate the figures are clearly not reliable. In the absence of a European wide systematic screening programme it is unlikely that all cases of contamination have been identified.

5.2.4 *Number of sites releasing PFAS*

Aggregation of the cost data to provide some estimate of damage at Nordic and EU scales requires additional data, provided in Annex 3, Part 2, covering:

- population
- water consumption
- quantity of water supplied from groundwater and surface water
- number of wastewater treatment plant (WWTP)
- number of plant or sources providing drinking water
- number of PFAS producers

- number of companies potentially using PFAS
- number of airports
- number of landfill and incineration sites.

Information covers the EU28, Norway and Iceland to the extent that data are available. Data for the USA are also included for reference, given that much of the information used in this report is of US origin. A summary of the number of sites releasing or potentially releasing PFAS is provided in Table 32 below, drawing on the information in Annex 3, Part 2.

Table 32: Number of installations working in the sectors that may use or emit PFAS for the EEA. Figures in brackets represent businesses with more than 250 employees

Sector	Activity	Total
Waste water treatment plant	T1 (primary treatment)	7,279
	T2 (secondary treatment)	24,316
	T3 (tertiary treatment)	19,716
	Of which T3N (T3 + nitrogen removal)	11,502
	Of which T3P (T3 + phosphorus removal)	10,436
Drinking water treatment	Large	Thousands
	Small	Ten thousands
	Very small	Hundred thousands
Aviation	Main passenger airports	318
	Medium passenger airports	137
	Small airports	no data
	Military airbases	239
Other fire control	Fire stations	84,099
	Site emergency services	no data
Waste	Hazardous waste landfill	365
	Non-hazardous waste landfill	3,801
	Large incineration (as energy from waste)	808
Manufacturing industry	PFAS manufacturers[1]	12–20
	Textiles	61,685 (262)
	Leather	37,120 (159)
	Carpet	no data
	Paper	19,477 (488)
	Paints and varnishes	4,027 (104)
	Cleaning products	(178)
	Cosmetics and personal care	no data
	Electronics	no data
	Photography films	no data
	Metal treatments	151,455 (163)
	Car washes	79,000
	Mining	no data
	Plastic, resins, rubbers	(340)

Note: 1) It has not proven possible to identify the European PFAS manufacturers with confidence. From data collected, it is assumed that there are between 12 and 20 sites, best estimate 16, distributed as follows: Belgium (2), Czechia (1), France (3), Germany (3), Italy (2), Netherlands (1), Poland (1), UK (3).

Not all of these enterprises, particularly in manufacturing, produce, use or emit PFAS. However, it can be concluded that the total number of sites emitting PFAS in some quantity could be in the order of 100,000 or more for the EEA. Information presented in Annex 3 demonstrates that these activities are not concentrated in a few countries but are spread throughout the region.

5.2.5 Extrapolation of costs, by country

Noting the uncertainties identified elsewhere in this report, a precise quantification of costs associated with PFAS contamination is not possible. Estimation of damage is, however, still an important exercise as it provides opportunity to describe the likely magnitude of economic damage. With this in mind, a scenario based assessment has been carried out.

The following elements are estimated, with results in this section provided for each of the Nordic countries and the EU28+Switzerland combined:

- costs of a screening programme
- costs of monitoring
- costs of water treatment
- costs of soil remediation
- costs of health assessment studies.

A full breakdown of results by country is provided in Annex 3, Part 3.

A key input to the assessment is based around the Swedish National Food Agency's limit value for PFAS in drinking water of 0.09 µg/l (90 ng/l) and techniques considered appropriate to treat contaminated water to meet that limit, and specifically the proportion of people exposed to levels above the limit value. Swedish data[359] indicates that this applies to between 2% and 3% of the Swedish population. The higher figure is selected here as the analyses have focused on 7 PFAS compounds rather than the 11 currently covered by the limit value: increasing the number of compounds will clearly increase the reported concentration and make exceedance of the limit more likely. A range of 1% to 5% is applied around this estimate. The assessment identifies the number of sites where significant contamination (i.e. in excess of the Swedish limit value) has been found and applies the proportion of the population with significant exposure indicated in the Swedish data.

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[359] Holmström *et al.* (2014). Nationell screening av perfluorerade föroreningar (PFAA) i dricksvatten. Rapport no 2014/20 (In Swedish).

Results are aggregated in the following tables to provide estimates for:

- the costs of a basic screening programme (Table 33);
- costs for monitoring at sites where significant PFAS contamination has been found (Table 34);
- costs for improvements to water treatment works to reduce exposure to PFAS above possible limits (Table 35);
- costs for soil remediation (Table 36);
- costs for health assessments when significant contamination is found (Table 37); and
- total of the above (Table 38).

The estimates are based on a number of assumptions which are summarised in the text below each table. Definition of low, best and high estimates is not straightforward, given limited data. In several cases the lower bound is based on data for Sweden because it provides the most complete infomation available for any country. Since this information only relates to contamination associated with the use of AFFFs at airfields it is likely to provide a lower bound: as other data in this report show, there are numerous other sources of PFAS contamination present in Europe including the manufacturing processes, the use and the disposal of contaminated waste materials. Ranges are provided along with best estimates based on the data in Table 30.

Estimated costs for a basic monitoring program are shown in Table 33. The assumptions used for the best estimate, and the low and high bounds, are given below the table. The best estimate indicates a cost in the order of EUR 14 million, in a range of EUR 2.8 to EUR 54 million.

Table 33: Estimated costs for a basic screening programme to assess PFAS levels

	N facilities for best estimate	Best estimate, EUR millions	Low, EUR millions	High, EUR millions
Denmark	78	EUR 0.08	EUR 0.02	EUR 0.31
Finland	184	EUR 0.19	EUR 0.06	EUR 0.65
Iceland	7	EUR 0.01	EUR 0.00	EUR 0.02
Norway	179	EUR 0.18	EUR 0.04	EUR 0.68
Sweden	411	EUR 0.42	EUR 0.12	EUR 1.50
Other EU28+CH	12,914	EUR 13.17	EUR 2.52	EUR 50.98
Total	*13,772*	*EUR 14.05*	*EUR 2.77*	*EUR 54.13*

Best estimate assumptions

1. All airports and PFAS manufacturing sites are screened, assume 3 samples, using best estimate of cost/sample for monitoring;
2. 5% of other facilities are screened (fire stations, waste water treatment works, large and small supplies, hazardous and MSW landfills), assume 3 samples;
3. Best estimate of costs adopted.

Low estimate assumptions

1. All airports and PFAS manufacturing sites are screened, assume 3 samples, using low cost/sample for monitoring.
2. 1% of other facilities are screened (fire stations, waste water treatment works, large and small supplies, hazardous and MSW landfills), assume 3 samples.
3. Low estimate of costs adopted.

High estimate assumptions

1. All airports and PFAS manufacturing sites are screened, assume 3 samples, using low cost/sample for monitoring.
2. 10% of other facilities are screened (fire stations, waste water treatment works, large and small supplies, hazardous and MSW landfills), assume 3 samples.
3. High estimate of costs adopted.

A number of factors could influence the costs estimated for such a screening programme, including the number of samples taken at each point, whether sampling is carried out once only or repeatedly over time, how the programme is organised, whether it is specific to PFAS or whether the opportunity is taken to investigate the presence of other contaminants, and so on.

Estimated costs for monitoring at contaminated sites are shown in Table 34.

Table 34: Estimated costs for monitoring at sites where significant PFAS contamination has been found

	N facilities for best estimate	Best estimate, airfields and PFASmanufacturing only, EUR-millions	Best estimate, all source categories included, EUR-millions	Low, EUR-millions	High, EUR-millions
Denmark	8	EUR 0.03	EUR 0.40	EUR 0.05	EUR 7.98
Finland	22	EUR 0.47	EUR 1.11	EUR 0.19	EUR 20.81
Iceland	1	EUR 0.04	EUR 0.05	EUR 0.01	EUR 0.86
Norway	19	EUR 0.20	EUR 0.97	EUR 0.13	EUR 18.87
Sweden	48	EUR 0.76	EUR 2.40	EUR 0.36	EUR 44.97
Other EU28+CH	1,327	EUR 5.46	EUR 66.36	EUR 7.57	EUR 1,322.66
Total	*1,426*	*EUR 6.96*	*EUR 71.28*	*EUR 8.30*	*EUR 1,416.13*

Best estimate assumptions

1. Assumed 20% of airports and airfields (as in Sweden) and PFAS manufacturing sites require monitoring programme, using best estimate cost/case for monitoring.
2. 0.5% of other facilities require monitoring.
3. Best estimate of costs adopted.

Low estimate assumptions

1. Assumed 10% of airports and PFAS manufacturing sites require monitoring programme, using low estimate cost/case for monitoring.
2. 0.1% of other facilities require monitoring.
3. Low estimate of costs adopted.

High estimate assumptions

1. Assumed 30% of airports and PFAS manufacturing sites require monitoring programme, using high estimate cost/case for monitoring.
2. 1% of other facilities require monitoring.
3. High estimate of costs adopted.

Table 34 separates the best estimate of cost associated with airfields and PFAS manufacturing from the best estimate taking into account all source categories. The total for airfields and PFAS manufacturing is only 10% of the total for the "all source" best estimate, but broadly in line with the low estimate. Summing the data from the literature review (Annex 3, Part 1) for existing monitoring at European sites where significant contamination has been found gives a cost of EUR 10.9 million, also of a similar order of magnitude to the calculated lower bound, though dominated by the Baden-Wurttemberg case. The likelihood of PFAS contamination being restricted to airfields and the small number of PFAS manufacturers present in Europe is unrealistic, hence a figure towards the best estimate does not seem unreasonable. Under the high estimate, results are almost totally dominated by sources others than airfield and PFAS manufacture because of the large number of potential sites (even though only 1% are considered). This position seems highly unlikely based on those countries where extensive monitoring has already been undertaken. However, the potential for more extensive contamination than is currently recognised exists, as shown by the case of Rastatt in Baden-Wurttemberg, Germany, where widespread contamination appears to have arisen from the spreading of waste paper materials on agricultural land, ironically for the purpose of soil improvement.[360]

The quantification of the costs associated with improvements to water treatment is carried out by consideration of the fraction of the Swedish population exposed to levels of PFAS in excess of the Swedish limit value. In line with the estimate given above, the best estimate is taken as 3% of the population. Broadly similar results were obtained for the USA, providing some level of verification on the order of magnitude of the estimate (though accepting the potential for coincidence, given the limited evidence base). The analysis then uses the estimates of cost/person in affected areas given in Table 35. Costs include both the upgrading of water treatment works and operation and maintenance over a 20 year period. The period of 20 years is selected to reflect that in some cases, perhaps most, advanced treatment of water supplies will be needed for many years to come, running to many decades unless remediation actions are possible and implemented.

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[360] https://www.faz.net/aktuell/wissen/baden-wuerttemberg-chemische-abfaelle-auf-dem-acker-14419295.html

In some cases, however, the need to use advanced water treatment may be reduced through connection to alternative uncontaminated supplies.

Table 35: Estimated costs for improvements to water treatment works to reduce exposure to PFAS above possible limits.

	Population affected, best estimate	Best estimate, EURmillions	Low, EUR millions	High, EUR millions
Denmark	170,000	EUR 97	EUR 7	EUR 274
Finland	160,000	EUR 93	EUR 7	EUR 265
Iceland	10,000	EUR 6	EUR 0	EUR 16
Norway	150,000	EUR 88	EUR 7	EUR 250
Sweden	290,000	EUR 166	EUR 13	EUR 472
Other EU28+CH	15,000,000	EUR 8,456	EUR 650	EUR 23,982
Total	*16,000,000*	*EUR 8,906*	*EUR 684*	*EUR 25,258*

Best estimate assumptions

1. Assumed 3% of the population are exposed to excess levels of PFAS via drinking water.
2. Assume 20 year maintenance programme for treatment works, based on best estimate.
3. Assume best estimate cost per case for water treatment.
4. Assume 4% discount rate on future maintenance costs.

Low estimate assumptions

1. Assumed 1% of the population are exposed to excess levels of PFAS via drinking water.
2. Assume 20 year maintenance programme for treatment works, based on best estimate.
3. Assume low estimate cost per case for water treatment.
4. Assume 4% discount rate on future maintenance costs.

High estimate assumptions

1. Assumed 5% of the population are exposed to excess levels of PFAS via drinking water.
2. Assume 20 year maintenance programme for treatment works, based on best estimate.
3. Assume high estimate cost per case for water treatment.
4. Assume 4% discount rate on future maintenance costs.

In comparison, the results from the identified literature gives a figure of EUR 136 million for improvements to water quality, only 20% of the lower bound calculated here. However, the costs identified in the literature are in many cases based on situations where measures are yet to be taken. Also, further costs are not considered in this estimate, for example, improvement of water treatment, the need to construct new water pipelines to bring in clean water from other areas, or the costs of shutting down existing wells and losing the water resource that they provide. Therefore, the estimated lower bound may not be unrealistic, and it is possible that the costs are substantially higher.

The results for individual countries will be more uncertain than the total estimate for the EEA countries. For example relative to Sweden the levels of contamination found in Denmark are much lower. This is likely linked to the distance between PFAS use and the location of the groundwater sources that dominate water supply. Table A3.9 in Annex 3 part 2 shows that 99% of drinking water in Denmark comes from ground rather than surface sources. This is a much higher percentage than in other countries. Extrapolation based on the Danish situation would therefore not account for the costs incurred already across Europe.

Estimated costs of soil remediation are given in Table 36, again with details on assumptions for the best, low and high estimates provided below the table.

Table 36: Estimated costs for soil remediation

	Number of sites affected for the best estimate	Best estimate, EUR millions, airfields and PFAS manufacturing only, EUR millions	Best estimate, EUR millions	Low, EUR millions	High, EUR millions
Denmark	8	EUR 3	EUR 40	EUR 0.5	EUR 798
Finland	22	EUR 47	EUR 111	EUR 2.2	EUR 2,081
Iceland	1	EUR 4	EUR 5	EUR 0.1	EUR 86
Norway	19	EUR 20	EUR 97	EUR 1.6	EUR 1,887
Sweden	48	EUR 76	EUR 240	EUR 4.3	EUR 4,497
Other EU28+CH	1,327	EUR 546	EUR 6,636	EUR 91	EUR 132,266
Total	*1,426*	*EUR 696*	*EUR 7,128*	*EUR 100*	*EUR 141,613*

Best estimate assumptions

1. Assumed 20% of airports and PFAS manufacturing sites require remediation.
2. 0.5% of other facilities require remediation.
3. Best estimate of costs adopted.

Low estimate assumptions

1. Assumed 10% of airports and PFAS manufacturing sites require remediation.
2. 0.1% of other facilities require remediation.
3. Low estimate of costs adopted.

High estimate assumptions

1. Assumed 30% of airports and PFAS manufacturing sites require remediation.
2. 1% of other facilities require remediation.
3. High estimate of costs adopted.

Of the estimates presented, soil remediation costs are likely to be the most uncertain, which is reflected in the range of the costs. The costs identified in the literature review for the Baden-Wurttemberg case alone are between EUR 1–3 billion[361], substantially more than the low estimate and almost half the best estimate. However, that cost is an estimate, and it is possible that more cost-effective solutions will be found. As noted above, Baden Wurttemberg is not the only location where high costs have been reported, with Schiphol and Dusseldorf Airports also reporting high remedation costs.

It is necessary to ask to what extent the costs of additional water treatment and soil remediation should be considered additive. It could be argued that with soil remediation carried out, there should be no need for additional water treatment, and vice-versa. However, this would ignore the time taken to carry out soil remediation, time during which water would need to be treated, or brought in from outside areas, to avoid excess exposure of the population. A failure to clean the soils would mean that water treatment would need to persist into the far future, rather than the 20 year period assumed here. Whilst there is some overlap it is clearly not a simple binary choice to treat water or remediate the soil, and both will often be necessary. A further factor to consider is that the longer soils are left contaminated, the more the PFAS will spread, potentially making clean-up more difficult, far more extensive and more expensive. Estimated costs for health assessments are provided in Table 37.

Table 37: Estimated costs for health assessments when significant contamination is found

	Population affected, best estimate	Best estimate, EUR millions	Low, EUR millions	High, EUR millions
Denmark	170,000	EUR 8.5	EUR 0.28	EUR 27
Finland	160,000	EUR 8.2	EUR 0.27	EUR 26
Iceland	10,000	EUR 0.5	EUR 0.02	EUR 1.6
Norway	150,000	EUR 7.7	EUR 0.26	EUR 25
Sweden	190,000	EUR 15	EUR 0.49	EUR 46
Other EU28+CH	14,000,000	EUR 744	EUR 24.79	EUR 2,355
Total	*15,000,000*	*EUR 783*	*EUR 26.11*	*EUR 2,480*

Best estimate assumptions

1. Assumed 3% of the population are exposed to excess levels of PFAS via drinking water.
2. Assume best estimate cost per case for remediation.

Low estimate assumptions

1. Assumed 1% of the population are exposed to excess levels of PFAS via drinking water.
2. Assume low estimate cost per case for remediation.

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[361] Cost data for this case are taken from http://greensciencepolicy.org/wp-content/uploads/2016/09/Rolland-Weber-PFOS-PFAS-German-activities-Final.pdf. A full, detailed account of the costing has not been identified. However, further accounts (e.g. https://www.faz.net/aktuell/wissen/baden-wuerttemberg-chemische-abfaelle-auf-dem-acker-14419295.html) refer to this case as the largest environmental scandal in Germany in terms of the area affected (currently arounf 400 hecatres).

High estimate assumptions

1. Assumed 5% of the population are exposed to excess levels of PFAS via drinking water.
2. Assume high estimate cost per case for remediation.

The need to undertake health assessment will vary from location to location. The cost of biomonitoring in Ronneby, Sweden averaged over EUR 0.5 million per year for a 3 year period. The WHO report health assessment costs for the Veneto region of EUR 4.6 million. On this basis, only a very small number of cases would be needed to reach the low estimate made here, so again, a figure between the low and best estimates is easily feasible.

5.2.6 Summary of environment-related costs of exposure to PFAS

Table 38 shows total costs from the preceding tables covering initial environmental screening, monitoring where contamination is found, water treatment, soil remediation and health assessment, with a more detailed breakdown for the Nordic countries in Table 39.

Table 38: Aggregated costs covering environmental screening, monitoring where contamination is found, water treatment, soil remediation and health assessment

	Best estimate, EUR millions	Low, EUR millions	High, EUR millions
Denmark	EUR 145	EUR 8	EUR 1,106
Finland	EUR 214	EUR 10	EUR 2,393
Iceland	EUR 12	EUR 1	EUR 105
Norway	EUR 194	EUR 9	EUR 2,181
Sweden	EUR 423	EUR 18	EUR 5,061
Other EU28+CH	EUR 15,915	EUR 776	EUR 159,976
Total	*EUR 16,902*	*EUR 821*	*EUR 170,821*

Table 39: Detailed breakdown for non-health environmental costs per Nordic Countries

	N people affected (3%)	Screening and monitoring	Health assessment	Upgrade treatment works and maintenance	Soil remediation	Total (EUR-millions)
Denmark	169,791	EUR 0.07–8.3	EUR 0.28–27	EUR 7.4–274	EUR 0–798	EUR 8–1,106
Finland	164,153	EUR 0.25–22	EUR 0.27–26	EUR 7.2–265	EUR 2.2–2,081	EUR 10–2,393
Iceland	10,102	EUR 0.01–0.9	EUR 0.02–1.6	EUR 0.4–1.6	EUR 0.1–86	EUR 1–105
Norway	154,995	EUR 0.17–20	EUR 0.26 –25	EUR 6.8–250	EUR 1.6–1,887	EUR 9–2,181
Sweden	292,421	EUR 0.48–47	EUR 0.49–46	EUR 13–472	EUR 4.3–4,497	EUR 18–5,061
Nordic total	*791,462*					*EUR 46–10,846*

Parallel calculations for all 31 EEA Member Countries and Switzerland arrive at a range of costs for environmental remediation totalling EUR 821 million to 170 billion. The uncertainties associated with these estimates are clearly high, reflecting the level of variation in the unit cost estimates. For example, remediation of just the one case of soil contamination in Germany at Baden-Wurttemberg has been estimated at EUR 3 billion, though this work has yet to be undertaken.

Uncertainties have been reviewed in the context of each of the tables presented. The lower and upper bounds should be considered illustrative because of the limited information available. Further analysis may be able to limit the range beyond that estimated here. However, based on the information from the literature review there is a firm basis for concluding that the lower bound estimates would be exceeded. A best estimate in the order of EUR 10–20 billion is certainly feasible. Significantly higher costs are feasible if several cases similar to the contamination at Baden-Wurttemberg are identified.

It is noted that results for individual countries will be more uncertain than results for Europe as a whole. It is, for example, understood that the contamination levels in Denmark are lower than Sweden. The situation in other countries may vary, with different levels of contamination. The data available from Sweden only link contamination to airports, whereas problems elsewhere have been identified in relation to other sources such as PFAS manufacture and use (Veneto), fires (Dusseldorf and Buncefield), and spreading of waste paper materials on agricultural land as a soil improver (Rastatt).

A further source of uncertainty concerns those elements of the analysis that have not been quantified. Notable amongst these are potential ecological effects, especially given the extreme persistence of PFAS. From an economic perspective the material reviewed above demonstrates public willingness to pay to avoid exposure to persistent and bioaccumulative substances, even without detailed assessment of impacts. Aggregated across the European population the willingness to pay based on information in the restriction proposal for D4 and D5 would be substantial in the order of billions of Euro and broadly comparable with the best estimate made here for monitoring and clean-up. The significant uncertainties in those estimates are recognised. Other elements that have not been quantified include the costs of providing new pipelines to provide access to uncontaminated water supplies and various administrative costs. The former, in particular, could be substantial based on evidence from a limited number of sites (e.g. Jersey, UK), certainly adding weight to the overall best estimate.

6. Conclusions

6.1 Findings and discussion

This study investigates the socioeconomic costs that may result from impacts on human health and the environment from the use of PFAS. Better awareness of the costs and long-term problems associated with PFAS exposure will assist authorities, policy-makers and the general public to consider more effective and efficient risk management. The production of PFAS, manufacture and use of PFAS-containing products, and end-of-life disposal of PFAS have resulted in widespread environmental contamination and human exposure. PFAS have been found in the environment all around the world and almost everyone living in a developed country has one or more PFAS in his/her body.

Because of the extreme persistence of PFAS in the environment, this contamination will remain on the planet for hundreds if not thousands of years. Human and environmental exposure will continue, and efforts to mitigate this exposure will lead to significant socioeconomic costs – costs largely shouldered by governments and taxpayers.

The focus of this study is on costs of inaction with respect to regulation of PFAS in the countries comprising the European Economic Area (EEA), i.e. the costs that society will have to pay in the future if action is not taken to limit PFAS-emissions today.

The impact pathway concept provides an overall analytical framework for the study. Five case studies, based on literature reviews, following the life-cycle of PFAS are presented to illustrate the links between production, use and disposal of PFAS, health and environmental exposures, and impacts and their economic valuation. The pathway concept provides a template for assessment of each source, enabling the analyst to consider which impacts are relevant.

The first three case studies cover the activities that account for a large proportion of the PFAS released into the environment: their production, their use in product manufacturing, and the use phase of PFAS-containing products. The industrial facilities producing the fluorochemicals and fluoropolymers, while relatively limited in number, are significant emitters of PFAS into the air, soil and waterways. Case Study 1 estimates that up to 20 facilities actively produce fluorochemicals in Europe, that these facilities are significant sources of PFAS released to the environment, and that exposure to workers at these plants is high.

Other industrial activities with the potential to release PFAS to the environment take place throughout Europe, including the Nordic region. Case Study 2 considers the manufacture and commercial use of PFAS-containing products, including textile and leather manufacturing; metal plating, including chromium plating; paper and paper product manufacturing; paints and varnishes; cleaning products; plastics, resins and rubbers; and car wash establishments. Releases of PFAS occur via the air or effluent entering sewerage and wastewater treatment plants, before discharge into waterways.

The third major source responsible for PFAS released to the environment, which is the focus of Case Study 3, is the widespread use of aqueous film-forming foams (AFFFs). The AFFFs are used to extinguish fires in emergencies or during training, especially around airports and military bases. Where the AFFFs have migrated to groundwater and other sources of drinking water, nearby communities have been affected by elevated levels of PFAS in their drinking water. It is noted that other uses of AFFFs for firefighting, especially at major industrial facilities, may also be a significant source, but one that has so far received little attention.

Case Study 4 and 5 considers the use and the end-of-life phase of consumer products, which account for the remaining releases and direct sources of exposure to PFAS. Case Study 4 looks at PFAS-treated carpets, PFAS-treated food contact materials and cosmetics as examples of how a product's use is likely to lead to human exposure. Possible exposure occurs through ingestion and dermal absorption, or through releases to the environment when the product is washed off or laundered, entering sewers, treatment plants, and eventually waterways. The availability of suitable non-fluorinated alternatives makes the use of PFAS in many of these products unnecessary.

Case Study 5 looks at end-of-life impacts of PFAS-treated products. Waste incineration may destroy PFAS in products if 1000 °C operating temperatures are reached, but such temperatures are not typical of most incineration capacity (the EU Industrial Emissions Directive, for example, requires a temperature of 850 °C for municipal waste incineration). If landfilled, the PFAS will remain even after the product's core materials break down. The compounds will eventually migrate into liquids in the landfill, then into leachate collection systems or directly into the natural environment. They may then enter drinking water supplies, be taken up by edible plants and bioaccumulate in the food chain.

6.1.1 Health-related costs to society

To calculate health-related costs to society, the study looked for consensus regarding health endpoints affected by exposure to PFAS. Some agreement has emerged concerning liver damage, increased serum cholesterol levels (related to hypertension), decreased immune response, increased risk of thyroid disease, decreased fertility, pregnancy-induced hypertension/pre-eclampsia, lower birth weight, and testicular and kidney cancer.

The methodology draws upon risk relationships developed in the course of specific epidemiological studies for populations exposed to PFAS at different levels. Workers exposed to PFAS in the workplace were used to exemplify a high level of exposure. Communities affected by PFAS, e.g. because of proximity to manufacturing sites or sites where fluorinated AFFFs were used were assumed to have been exposed at a medium level; this level of exposure was assumed to have been experienced by 3% of the European population. The general population was considered to have experienced exposure at low (background) levels.

Table 40 provides an overview of the estimated annual costs for just a few health endpoints where risk ratios were available for affected populations. Despite the high level of uncertainty and the assumptions underlying the calculations, the findings suggest that the health-related costs of exposure to PFAS are substantial.

Table 40: Estimated health-related costs of exposure to PFAS at different levels of exposure

Exposure level	"Exposed" population and source of PFAS	Health endpoint linked to PFAS	Nordic countries		All EEA countries	
			Population at risk	Annual costs	Population at risk	Annual costs
Occupational (high)	Workers at chemical production plants or manufacturing sites	Kidney cancer	n.a.	n.a.	84,000–273,000	EUR 12.7–41.4 million
Elevated (medium)	Communities near chemical plants, etc. with PFAS in drinking water	All-cause mortality	621,000	EUR 2.1–2.4 billion	12.5 million	EUR 41–49 billion
		Low birth weight	8,843	136 births of low birth weight	156,344	3,354 births of low birth weight
		Infection	45,000 children	84,000 additional days of fever	785,000 children	1.5 million additional days of fever
Background (low)	Adults in general population (exposed via consumer products, background levels)	Hypertension	10.3 million	EUR 0.7–2.2 billion	207.8 million	EUR 10.7–35 billion
Totals			*Nordic countries*	*EUR 2.8–4.6 billion*	*All EEA countries*	*EUR 52–84 billion*

The range of estimated annual health-related costs due to PFAS exposure is *EUR 2.8–4.6 billion for the five Nordic countries and EUR 52–84 billion for all EEA countries*. Some overlap occurs in the figures, because workers and affected communities are also exposed to background levels of PFAS. The actual costs are likely to be higher, since these calculations are for only a few of the health impacts linked to exposure to PFAS.

6.1.2 Non-health costs related to environmental contamination

The second methodology compiled information on direct costs incurred by communities taking measures to reduce PFAS exposure through remediation of drinking water. Based on these direct costs, ranges of cost per persons affected or per case were developed. These unit costs then became the foundation for aggregating the costs of remediation for environmental exposure over and above action levels for PFAS concentrations in drinking water.

As with the health-based estimates, the study assumes that 3% of the European population is exposed to drinking water with PFAS concentrations over regulatory action levels, such that the water treatment works serving them will require upgrading and maintenance over the next 20 years. Recognising the uncertainties that exist in the analysis and the available data, costs of remediation have been quantified using a scenario-based approach. For each scenario a number of parameters are specified, relating for example to the size of the affected population and the duration of maintenance works, and results generated accordingly.

Table 41 shows the range of costs for the various categories of actions related to environmental remediation for the five Nordic countries. The overall range of estimated non-health costs is *EUR 46 million – 11 billion over the next 20 years*, just for the Nordic countries. The upper end of this range is dominated by soil remediation costs for which associated uncertainty must be considered high.

Table 41: Detailed breakdown of ranges in quantified non-health costs for the Nordic countries.

	N people affected (3%)	Screening and monitoring	Health assessment	Upgrade treatment works and maintenance	Soil remediation	Total
Denmark	169,791	EUR 70,000–8.3 million	EUR 280,000–27 million	EUR 7.4 million–274 million	EUR 0–798 million	EUR 8 million–1.1 billion
Finland	164,153	EUR 250,000–22 million	EUR 270,000–26 million	EUR 7.2 million– 265 million	EUR 2.2 million–2.1 billion	EUR 10 million–2.4 billion
Iceland	10,102	EUR 10,000–900,000	EUR 20,000–1.6 million	EUR 400,000–1.6 million	EUR 100,000–86 million	EUR 1 million–105 million
Norway	154,995	EUR 170,000–20 million	EUR 260,000–25 million	EUR 6.8 million– 250 million	EUR 1.6 million – 1.9 billion	EUR 9 million–2.2 billion
Sweden	292,421	EUR 480,000–47 million	EUR 490,000–46 million	EUR 13 million–472 million	EUR 4.3 million – 4.5 billion	EUR 18 million–5.1 billion
Nordic total	*791,462*					*EUR 46 million–11 billion*

The cost estimates provided in the table are likely to be more robust at the aggregate, European level than at the national level, given the potential for significant variation between countries in sensitivity and use of PFAS, that could not be accounted for here.

Parallel calculations for all 31 EEA Member Countries and Switzerland arrive at a range of non-health costs for environmental remediation totalling *EUR 821 million to EUR 170 billion*. Again, these cost estimates will be more robust at the aggregate, European level than at the national level. A review of the uncertainties concludes that the lower and upper bounds should be considered illustrative because of the limited information currently available, reflecting the level of variation in the unit cost estimates. However, based on the information from the literature review there is a firm basis for concluding that the lower bound estimates would be exceeded. A *best estimate in the order of EUR 10–20 billion* is certainly plausible. Significantly higher costs than that are likely if several cases similar to the contamination at Baden-Wurttemberg are identified, where costs of soil remediation have been estimated at up to EUR 3 billion.

A number of other costs related to PFAS contamination are outside the scope of the quantification carried out in this report. These include loss of property value, reputational damage to a polluting company, costs of short-term measures such as provision of bottled water, ecological damage and the costs incurred by public authorities in responding to affected communities – including public outreach, surveys of contamination, and remedial measures.

6.1.3 Conclusions

The work of estimating the health and environment-related costs to society related to PFAS exposure has relied on the development of assumption-based scenarios. This reflects the limited data available in the academic literature, government documents and press reports.Whilst the uncertainties of the analysis need to be acknowledged, it is also important to recognise that, for a number of issues, there is little or no uncertainty. For example, that the equivalent of hundreds of millions of EUR have already been spent on remediation of PFAS contamination, that PFAS use is widespread, and that PFAS will persist in the environment for an extremely long time. Other certainties include:

1. PFAS are ubiquitous in the environment, and almost all people have PFAS in their bodies today. Monitoring in both Sweden and the USA concludes that around 3% of the population are or have been exposed above proposed limit values, primarily through contamination of drinking water but also via other sources.
2. Many sources of PFAS exposure exist linked to specialist applictaions (e.g. AFFFs for firefighting at aairports and some industrial loctaions) and non-specialist uses (e.g. use in consumer goods such as ing, cosmetics and pizza boxes).
3. Non-fluorinated alternatives for many of these uses are already on the market, and therefore certain uses of PFAS can be reduced.
4. The costs for remediating some cases of contamination run to many millions of EUR. Total costs at the European level are expected to be in the hundreds of millions of EUR as a minimum.
5. A large and growing number of health effects have been linked to PFAS exposure and evidence is mounting that effects occur even at background level exposures.

Current and proposed limit values for drinking water may be further reduced in recognition of growing information on, health and environmental risks. This would increase the costs of environmental remediation estimated here.

As explained throughout the study, the calculations rest on a number of assumptions, though these have been checked against (e.g.) data on costs incurred to ensure that they are linked to real-world experience. As more information becomes available in the future, drawing on the framework provided here, calculations will become more precise. Moreover, these findings are conservative. The figures will only get larger, in that the numbers of PFAS on the market and the volumes produced keeps increasing. Further inaction will lead to more sources of contamination, more people exposed, and higher costs for remediation. The longer that PFAS contamination is left in the environment, the wider it will spread and the greater the quantity of soil or groundwater that will need to be decontaminated.

6.2 Next steps and proposals for further studies

As with other studies seeking to identify costs of inaction linked to chemicals exposure, our findings have been hampered by a lack of data concerning contamination and levels of human exposure. Overall calculations rest on a number of assumptions which may become more precise as more information is available in the future. Additional research to help gather this additional information could include:

- consideration of health endpoints due to exposures to groups of PFAS, since exposures are rarely limited to a single PFAS and since PFAS as a group share similar properties – most importantly, the property of extreme persistence in the environment;
- more information concerning the sites where production of PFAS and/or where manufacturing of manufacturing of products involving PFAS is, or have been occurring. National inventories of such sites are needed, including of sites where fluorinated AFFFs have been used. This would be of great help in estimating the numbers of affected populations, and the extent of contamination where remediation may be needed;
- systematic cataloguing of cost data where problems have been identified;
- inclusion of industries producing or using PFAS in the European Pollutant Release and Transfer Register, so that information on the location of releases to air and to water is available and so those releases can be tracked;
- national registries of products containing PFAS to help inform how PFAS are used and to contribute to better characterisation of the major sources of exposure from products;
- drinking water standards using group parameters for PFAS, so as to require better monitoring of drinking water. This will provide early warnings when elevated levels are found and enable more effective identification and timely containment of sources of contamination;
- better understanding of what happens to PFAS discharged from wastewater treatment plants and during incineration, including assessment of ecological risks from PFAS contamination; and
- more biomonitoring and epidemiological studies to characterize links between PFAS exposure and health endpoints, to enable better calculations of associated health costs.

As this study highlights, the release of PFAS into the environment and constant exposure of humans is ongoing throughout the Nordic countries and Europe. Large-scale monitoring efforts such as those carried out in Sweden can help to clarify sources of contamination and provide more certainty concerning the scale of the socio-economic costs related to PFAS exposure. This will help to better inform policymakers, industry and consumers concerning the actions needed.

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Sammanfattning

Högfluorerade ämnen (PFAS) kan skada människors hälsa och miljön. Förutom att orsaka ett stort lidande för drabbade individer medför denna exponering stora kostnader för samhället. I den här studien uppskattas kostnader för samhället som användningen av PFAS kan orsaka på grund av dess påverkan på miljön och människors hälsa. En större medvetenhet om kostnader och långsiktiga problem som kan förknippas med användningen av högfluorerade ämnen kan hjälpa berörda myndigheter, beslutsfattare och allmänheten att ta beslut om effektiva och riskminskande åtgärder.

I studien granskas hur produktionen av PFAS, tillverkningen och användningen av produkter som innehåller PFAS samt hur sluthanteringen av dessa har resulterat i omfattande miljöförorening och exponering av människor. PFAS har hittats i miljön över hela världen och nästan alla som lever i ett land med utvecklad ekonomi har ett eller flera PFAS-ämnen i sin kropp.

Eftersom de högfluorerade ämnena är så långlivade i miljön kommer dessa ämnen att finnas kvar på vår planet i hundratals, om inte tusentals år. Människors och miljöns exponering för PFAS kommer att fortsätta, och åtgärder för att minska denna exponering kommer medföra stora kostnader för samhället. Det är kostnader som till stor del ska betalas av offentliga myndigheter och skattebetalare.

I rapporten studeras kostnader som samhället kommer att behöva betala i framtiden om åtgärder inte genomförs för att begränsa utsläppen av PFAS. Studien fokuserar på de länder som ingår i det Europeiska Ekonomiska Samarbetsområdet (EES). "Cost of inaction" definieras som de kostnader som samhället i framtiden kommer att behöva betala om inga åtgärder genomförs idag för att begränsa utsläppen av PFAS. De PFAS som omfattas i den här studien är fluorerade ytaktiva ämnen med en kolkedjelängd av C4-C14. Studiens målsättning var att ta fram:

1. Ett ramverk för att uppskatta samhällskostnader kopplade till negativa effekter på hälsa och miljö i samband med exponering för PFAS.
2. Monetära värden för dessa samhällskostnader, dokumenterade genom fallstudier.

Slutsatser

För att uppskatta de hälsorelaterade och miljömässiga kostnader för samhället utgick vi från scenarier som bygger på antaganden, eftersom tillgången på data är så begränsad. Studien baserar sig på litteratur, information från myndigheter och nyhetsartiklar. Även om studien och dess analys innebär vissa osäkerhetsfaktorer finns det en relativt stor säkerhet i en rad frågor:

1. PFAS förekommer överallt i miljön och nästan alla människor har PFAS i sina kroppar. Mätningar från både Sverige och USA visar att cirka tre procent av befolkningen exponeras för halter som ligger över de rekommenderade gränsvärdena, framförallt via dricksvatten men andra källor förekommer också.
2. PFAS kan hamna i miljön och i människor på många olika sätt. En källa till spridning av PFAS i miljön är via, till exempel användningen av brandsläckningsskum för brandbekämpning på flygplatser och på vissa industrianläggningar. PFAS sprids då till miljön och når slutligen dricksvattnet. PFAS kan också spridas via användningen i konsumentvaror så som exempelvis pizzakartonger, kläder och kosmetiska produkter.
3. För många av de områden där PFAS idag används finns redan icke-fluorerade alternativ tillgängliga på marknaden. Därför skulle vissa användningar redan idag kunna minskas.
4. Kostnaden för att sanera mark och vatten uppskattas till många miljoner EUR. Den totala saneringskostnaden för EUs medlemsländer uppskattas till minst hundratals miljoner EUR.
5. De negativa hälsoeffekter som kan bero på exponering för PFAS är redan många och fortsätter dessutom att öka i antal. Det finns också bevis för att det kan uppstå negativa effekter redan vid exponering för relativt låga halter även vid halter motsvarande låga (bakgrunds) nivåer.

De rekommenderade gränsvärdena för dricksvatten kan komma att sänkas ytterligare när mer information om risker för hälsa och miljö tas fram. Detta skulle öka kostnaderna för den miljösanering som uppskattats i denna studie.

Beräkningarna i studien grundar sig på ett antal antaganden. Dessa antaganden har stämts av mot faktiska kostnadsuppgifter för att säkerställa att de är kopplade till verkliga fall. Allteftersom mer information blir tillgänglig kommer beräkningarna kunna bli mer exakta. I den här studien har vi varit försiktiga i våra antaganden, resultaten visar därför på kostnader som sannolikt inte kan vara lägre, däremot skulle de kunna vara högre. Det är troligt att kostnaderna kommer att öka i takt med att förhöjda volymer och ett ökat antal PFAS finns tillgängliga på marknaden.

Att vänta ännu längre med att begränsa utsläppen av PFAS kan få stora konsekvenser. Det kan innebära att antalet utsläppskällor ökar, att fler personer exponeras och att kostnaderna för saneringen blir högre. Föroreningarna kommer också att sprida sig, vilket medför att större mängder mark och/eller grundvatten kommer att behöva saneras.

Metod

Två metoder har utvecklats under arbetet med denna rapport. Båda metoderna är baserade på fallstudier som berör exponeringen av PFAS. Den ena metoden används för att bedöma hälsorelaterade kostnader. Den andra metoden används för att beräkna kostnaderna för miljösanering. Data specifik för de nordiska länderna har använts när sådana har funnits, men uppskattningarna bygger också på information från andra europeiska länder, USA och Australien.

Spridningsvägar (fallstudier)

För att illustrera hur exponeringen av människor och miljö ser ut har fem fallstudier som följer PFAS livscykeln (från produktion och användning vid produkttillverkning till produkters användning och sluthantering) använts. För att få ytterligare uppgifter om direkta kostnader som uppstått i samband med till exempel behovet att sanera förorenat dricksvatten har även andra fall av PFAS-föroreningar studerats.

I fallstudie 1 studeras produktionen av PFAS i Europa och vilka föroreningar denna har orsakat. Här granskas föroreningar som är kopplade till Chemours fabriker i Dordrecht (Nederländerna); Mitenis anläggning i Veneto-regionen (Italien); och 3Ms anläggning nära Antwerpen (Belgien). Studien uppskattar att upp till 20 anläggningar aktivt producerar fluorokemikalier i Europa samt att dessa anläggningar är betydande källor till utsläpp av PFAS till miljön. Studien visar också att exponeringen för arbetare vid dessa anläggningar är hög.

Fallstudie 2 handlar om tillverkning samt användning av produkter som innehåller PFAS. Industriella aktiviteter som kan släppa ut PFAS till miljön inkluderar textil- och lädertillverkning; metallplätering, inklusive kromplätering; tillverkning av papper och pappersvaror; färger och lacker; rengöringsprodukter; plast, hartser och gummi; samt biltvättar. I studien antas att ett intervall på 3–10 procent av dessa anläggningar använder PFAS. Några fluorokemiska produktionsanläggningar i de nordiska länderna kunde inte identifieras. Däremot visar statistik från Eurostat att annan industriell verksamhet som riskerar att släppa ut PFAS till miljön äger rum i regionen, såsom metallplätering och tillverkning av papper- och pappersvaror.

I fallstudie 3 och 4 studeras användningen av kemiska produkter och varor som innehåller PFAS. Vattenbaserade filmbildande skum (AFFF) som innehåller PFAS har använts för att släcka petroleumbaserade bränder samt i brandövningar, vilket har orsakat att grundvatten förorenats – särskilt kring flygplatser och militära baser. Även närliggande samhällen har påverkats av förhöjda nivåer av PFAS i dricksvattnet. I fallstudie 4 studeras användningen av varor och produkter som innehåller PFAS så som mattor, livsmedelsförpackningar och kosmetiska produkter. Dessa varor och produkter används som exempel för att visa hur användningen av en vara sannolikt kan leda till att människor exponeras via livsmedel och absorption genom huden. Användningen leder också till utsläpp av PFAS till miljön när produkter sköljs av eller rengörs och når avloppsnät, reningsverk och så småningom recipient.

I fallstudie 5 studeras effekterna från sluthanteringen av produkter som innehåller PFAS. Kommunal avfallsförbränning kan destruera PFAS i produkter vid driftstemperaturer på 1000°C, men vid deponering kommer PFAS att finnas kvar även efter att produktens kärnmaterial brutits ner. Föreningarna kommer så småningom förflytta sig till vätskor i deponin, och därefter till uppsamlingssystem för lakvatten eller direkt till grundvatten och mark. De kan sedan nå dricksvattentäkter eller tas upp av växter och bioackumuleras i livsmedelskedjan.

Hälsorelaterade samhällskostnader

För att beräkna hälsokostnader för samhället har studien sökt efter konsensus om hälsoeffekter kopplade till exponering för PFAS. De vetenskapliga bevis som finns är motstridiga, men viss konsensus verkar råda vad gäller leverskador, höga blodtrycksnivåer, nedsatt immunförsvar (högre infektionsrisk), ökad risk för sköldkörtelsjukdom, nedsatt fertilitet, graviditetsinducerad hypertoni, preeklampsi, lägre födelsevikt, samt testikel- och njurcancer.

Metoden bygger på riskrelationer från epidemiologiska studier för populationer som i olika hög grad exponerats för PFAS. Arbetare som exponerats för PFAS på arbetsplatsen är exempel på en grupp med en hög exponeringsnivå, medan samhällen som drabbats av PFAS på grund av närheten till produktionsanläggningar, eller där fluorerade AFFF använts, antas ha exponerats på medelnivå. Denna exponeringsnivå antas gälla för tre procent av den europeiska befolkningen, medan befolkningen i övrigt antas ha exponerats för låga (bakgrunds-) nivåer.

Tabell 42 ger en översikt över de uppskattade årliga kostnaderna för ett antal hälsoeffekter där riskkvoter fanns tillgängliga för berörda populationer. Exempelvis bedömdes den årliga hälsorelaterade kostnaden för förhöjd risk för njurcancer p.g.a. yrkesmässig exponering för PFASs uppgå till mellan EUR 12,7 och EUR 41,4 miljoneri EES-länderna.[362] Den uppskattade hälsorelaterade kostnaden blev betydligt högre för såväl förhöjda som bakgrundsnivåer p.g.a. det stora antalet personer som då berörs. Den årliga hälsorelaterade kostnaden för exponering vid tre olika nivåer av PFASs beräknades till minst EUR 2,8–4,6 miljarder i de nordiska länderna och EUR 52 till EUR 84 miljarder i EES-länderna. Trots stora osäkerheter och att beräkningarna till stor del baseras på antaganden så tyder resultaten på att hälsokostnaderna för PFASs-exponering är betydande.

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[362] P.g.a. ofullständiga data gällande antal och lokalisering av produktionsanläggningar för kemikalier och produkter innehållande kemikalier har de hälsorelaterade kostnaderna, orsakade av yrkesmässig exponering för PFAS i de nordiska länderna, inte kunnat beräknas.

Tabell 42: Uppskattade årliga hälsorelaterade kostnader vid exponering av PFAS

Exoneringsnivå	Exponerad population & källa	Hälso endpoint	Nordiska länder		Alla EEA länder	
			Exponerad population	Årlig kostnad	Exponerad population	Årlig kostnad
Yrkesmässig (hög)	Arbetare på kemiska produktionsanläggningar eller tillverkningsställen	Njurcancer	Ej tillgängligt	Ej tillgängligt	84000–273000	EUR 12,7–41,4 miljoner
Förhöjd (medium)	Samhällen nära kemiska anläggningar etc. med PFAS i dricksvattnet	Dödlighet (alla orsaker)	621000	EUR 2,1–2,4 miljarder	12,5 miljoner	EUR 41–9 miljarder
		Låg födelsevikt	8843 födslar	136 födslar med låg födelsevikt	156344 födslar	3354 födslar med låg födelsevikt
		Infektion	45000 barn	84000 ytterligare dagar med feber	785000 barn	1,5 miljoner ytterligare dagar i feber
Bakgrund (låg)	Vuxna i den allmänna befolkningen (exponerade via konsumentprodukter, bakgrundsnivå)	Hypertoni	10,3 miljoner	EUR 0,7–2,2 miljarder	207,8 miljoner	EUR 10,7–35 miljarder
Totalt			*Nordiska länder*	*EUR 2,8–4,6 miljarder*	*Alla EEA länder*	*EUR 52–84 miljarder*

Anm.: Årligt antal berörda personer är det uppskattade antalet individer med en ökad risk för negativa hälsoeffekter på grund av olika exponeringsnivåer.

En viss överlappning förekommer i uppgifterna ovan, eftersom arbetstagare och drabbade samhällen också utsätts för bakgrundsnivåer av PFAS. Samtidigt är dessa kostnader troligen underskattade på grund av bristen på epidemiologiska riskrelationer att använda för beräkning av andra hälsoeffekter och relaterade kostnader.

Icke hälsorelaterade samhällskostnader (miljörelaterade)

Den andra metoden innefattade att samla information om direkta kostnader som uppstått i samhällen där åtgärder, såsom rening av dricksvatten, vidtagits för att minska människors exponering för PFAS. Med dessa sammanlagda kostnader som grund beräknades kostnadsintervall per person eller per fall. Dessa enhetskostnader användes sedan för att räkna samman kostnaderna för sanering när miljöexponeringen, till exempel koncentrationer i dricksvatten, överskrider vissa nivåer. Det bör noteras att intervallen som anges i tabellen är stora, även när de normaliserats mot populationen.

Avgörande för om intervallen för medelvärden kan beräknas beror på vilken mängd data som finns tillgängliga. När det exempelvis gäller kostnaderna för att rena vatten fanns ett flertal estimat tillgängliga. I ett sådant fall är det osannolikt att det faktiska medelvärdet kommer att vara ett extremvärde i någon av intervallets ändar som hämtats från studierna. Det är därför rimligt att minska det observerade intervallet till exempel genom att ta bort de uppskattningar som redan i tillräckligt stor omfattning exkluderats från andra datakällor, det vill säga att de är att betrakta som avvikande värden. För vissa kostnader finns dock mycket få uppskattningar tillgängliga. Var och en av de tillgängliga uppskattningarna kan vara lika gällande för att ange medelvärdet. I ett sådant fall antas det observerade värdeintervallet som ett intervall för troliga medelvärden.

I de fall då inget intervall finns att hämta från källorna i litteraturstudien har ett intervall uppskattats som till exempel intervallet +/- 90 % som används för att upprätta ett hälsovårdsprogram (definieras ej som en hälsokostnad i denna rapport då den avser hantering av problemet och inte effekter på människors hälsa). I det här exemplet är det angivna intervallet stort av två anledningar; dels på grund av bristen på tillgängliga data samt på grund av den möjliga variationen i genomförande av hälsovårdsprogram.

Liksom för de hälsorelaterade uppskattningarna har studien antagit att 3 % av den Europeiska befolkningen är exponerad för dricksvatten med PFAS-halter över de reglerade åtgärdsnivåerna, vilket gör att de vattenreningsverk som förser denna del av befolkningen med dricksvatten kommer att behöva förbättras och underhållas de närmsta 20 åren. Antagandet om 20 år återspeglar möjligheten att saneringen ska kunna lösa problemen, kanske genom rening eller användning av alternativ eller möjligheten för att saneringsåtgärder pågår under många år. På grund av de osäkerheter som finns i analysen och tillgängliga data har kostnader för sanering kvantifierats med hjälp av en scenariobaserad metod. För varje scenario har ett antal parametrar specificerats, exempelvis storleken av den drabbade befolkningen och tidsåtgången för underhållsarbete.

Tabell 43 visar kostnadsintervallen för olika kategorier av åtgärder kopplade till arbetet med att återställa och rena miljön.

Tabell 43: Summerade kostnadsuppgifter för icke-hälsorelaterade utgifter, över 20 år,

Vidtagen åtgärd vid fynd av PFASs	Enhet	Bästa uppskattning	Intervall från studier	Använt intervall
Övervakning av kontaminering från industriell användning eller AFFF	Kostnad per vattenprov	EUR 340	EUR 278–402	EUR 278–402
	Kostnad/fall av kontaminering	EUR 50000	EUR 5200–5,8 miljoner	EUR 25000–500000
Hälsobedömning (inklusive bioövervakning)	Kostnad/person	EUR 50	Inget intervall	EUR 5–95 (+/-90 %)
	Total bioövervakning & hälsobedömning per fall där så ansetts lämpligt	EUR 3,4 miljoner	EUR 2,5 miljoner–4,3 miljoner	EUR 1 miljoner–5 miljoner
Temporärt tillhandahållande av oförorenad resurs	Kostnad/person	Inga relevanta data		
Installering av ny pipeline	Kostnad/person	EUR 800	EUR 37–5000	EUR 100–1500
Uppgradering av vattenverk (kapital)	Kostnad/person	EUR 300	EUR 8–2200	EUR 18–600
Uppgradering av vattenverk (underhåll)	Kostnad/person	EUR 19	EUR 8–30	EUR 8–30
Utgrävning och behandling av jord kontaminerad genom industriell eller AFFF användning	Kostnad/kg PFASs	EUR 280000	EUR 100000–4,3 miljoner	EUR 100000–1 miljoner
	Kostnad/fall	EUR 5 miljoner	EUR 100000–3 miljarder	EUR 300000–50 miljoner

Tabell 44 visar kostnadsintervall för olika åtgärdskategorier relaterade till miljösanering för de fem nordiska länderna. Sammantaget rör det sig om ett kostnadsintervall på 46 miljoner–11 miljarder EUR.

Tabell 44: Detaljerad översikt av intervall för de Nordiska länderna, med antagande att 5 % (bästa uppskattning 3 %) av populationen/befolkningen exponeras med halter över gällande gränsvärden och att vattenrening behövs under en 20 års period.

	Antal exponerade personer (3 %)	Screening & övervakning	Hälsobedömning	Uppgradering av vattenverk & underhåll	Marksanering	Totalt
Danmark	170000	EUR 70000–8,3 miljoner	EUR 280000–27 miljoner	EUR 7,4 miljoner–274 miljoner	EUR 0–798 miljoner	EUR 8 miljoner–1,1 miljarder
Finland	160000	EUR 250000–22 miljoner	EUR 270000–26 miljoner	EUR 7,2 miljoner–265 miljoner	EUR 2,2 miljoner–2,1 miljarder	EUR 10 miljoner–2,4 miljarder
Island	10000	EUR 10000–900000	EUR 20000–1,6 miljoner	EUR 400000–1,6 miljoner	EUR 100000–86 miljoner	EUR 1 miljoner–105 miljoner
Norge	160000	EUR 170000–20 miljoner	EUR 260000–25 miljoner	EUR 6,8 miljoner–250 miljoner	EUR 1,6 miljoner–1,9 miljarder	EUR 9 miljoner–2,2 miljarder
Sverige	290000	EUR 480000–47 miljoner	EUR 490000–46 miljoner	EUR 13 miljoner–472 miljoner	EUR 4,3 miljoner– 4,5 miljarder	EUR 18 miljoner– 5,1 miljarder
Norden totalt	*790000*					*EUR 46 miljoner– 11 miljarder*

Kostnadsberäkningarna som anges i Tabell 44 är sannolikt mer robusta för den sammanlagda europeiska nivån än för den nationella nivån.

Tabell 45 visar sammanlagda kostnader för miljöscreening, övervakning (där föroreningar har hittats), vattenrening, marksanering och hälsobedömning för de fem nordiska länderna samt för övriga EES-länder och Schweiz.

Tabell 45: Sammanlagda kostnader för miljöscreening, övervakning när föroreningar upptäckts, vattenrening, marksanering och hälsobedömningar

	Bästa uppskattning	Låg	Hög
Danmark	EUR 145 miljoner	EUR 8 miljoner	EUR 1,1 miljarder
Finland	EUR 214 miljoner	EUR 10 miljoner	EUR 2,4 miljarder
Island	EUR 12 miljoner	EUR 1 miljoner	EUR 105 miljoner
Norge	EUR 194 miljoner	EUR 9 miljoner	EUR 2,2 miljarder
Sverige	EUR 423 miljoner	EUR 18 miljoner	EUR 5,1 miljarder
Övriga EES+CH	EUR 15,9 miljarder	EUR 776 miljoner	EUR 159,9 miljarder
Totalt	*EUR 16,9 miljarder*	*EUR 821 miljoner*	*EUR 170,8 miljarder*

Motsvarande beräkningar för alla 31 EES-länder och Schweiz ger ett kostnadsintervall för miljösanering på EUR 821 miljoner till EUR 170 miljarder. De lägre och övre gränserna bör betraktas som symboliska på grund av den begränsade information som är tillgänglig. Baserat på informationen från litteraturstudien finns det anledning att tro att de nedre gränserna kommer överskridas. En uppskattning i storleksordningen EUR 10–20 miljarder är säkerligen rimlig. Troligtvis kan betydligt högre utgifter än så komma ifråga om flera fall med miljardkostnader för marksanering identifieras. En uppskattning av kostnaderna för ett fall som identifierats i samband med en studie gällande staden Rastatt i

Baden-Wurttemberg i Tyskland ligger inom intervallet EUR 1 till EUR 3 miljarder, ett intervall som antas komma att öka i omfattning med tiden. I detta fall anses källan till utsläppen ha varit förorenat material av återvunnet papper som spreds ut på jordbruksmark. Detta visar att allvarliga problem inte alltid är kopplade till flygfält och tillverkning av PFAS.

Ett antal andra kostnader relaterade till förorening av PFAS ligger utanför denna studies avgränsning och kvantifiering. Dessa inkluderar minskat värde på egendom, försämrat rykte för företag som förorenar, ekologiska skador, samt kostnader för att åtgärda förorenade områden som belastar berörda myndigheter – vilket inkluderar att informera allmänheten, att analysera förekomst av föroreningar samt att vidta saneringsåtgärder.

Annex 1: National / state screening for PFAS contamination

This annex reviews the efforts of several EEA Member States and the USA to screen their territories to determine where PFAS contamination may pose risks to health and the environment. Two approaches for such screening can be distinguished. One approach is to identify the types of uses of PFAS that might lead to releases to the environment and then test water and soil in nearby areas for contamination. The other approach is to carry out comprehensive testing of drinking water supplies or wastewater treatment plant discharges and, if PFAS contamination is detected at levels of concern, to work upstream to identify the source of the contamination.

Denmark

Groundwater is the major source of drinking water in Denmark. Denmark therefore regularly monitors groundwater, under a program called GRUMO[363],_as well as the wells supplying waterworks. A 2014 screening investigation looked for the presence of 7 PFAS in groundwater where uses of PFAS may have led to contamination[364] (Denmark has no direct production of PFAS). It drew on a 2005 survey of annual consumption of PFAS that estimated, of a total of 9–16 tonnes used that year, 50% was used in various textile, leather and paper products. PFOS and other PFAS were also used in paints and varnishes, in cleaning and polishing products, and in electroplating. Chromium plating was also targeted, since it was considered the largest consumer of PFOS in Europe at the time. Table A1.1 lists the industries and activities identified as potential sources of contamination, the numbers of screening investigations, and any PFAS contamination of groundwater identified in the 2014 screening report.

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[363] Geological Survey of Denmark and Greenland, Monitoring Programmes.

[364] Danish Ministry of Environment (2014). Screeningsundersøgelse af udvalgte PFAS-forbindelser som jor- og grundvandsforureng i forbindelse med punktkilder, Miljøprojekt nr. 1600.

Table A1.1: Number of sites identified as potential sources of contamination and overview

Industry/activity	No. sites investigated	PFAS in groundwater?	Concentration levels
Fire training facilities	8 sites	Yes	2 sites ~ 100 ng/l 2 sites - >1000 ng/l 4 sites – none found
Chromium plating	2 sites	No	na
Carpet industry	1 site	Yes	1500 ng/l
Paint industry	1 site	No	na
Landfills	4 sites	No	na

The investigation confirmed that fire drill sites were confirmed as potential sources of PFAS contamination, and recommended surveying the other large fire drill sites in Denmark that had used PFAS-containing aqueous film-forming foams (AFFFs). It reported on a comprehensive site investigation performed at another site (Copenhagen airport) that found concentrations of PFOS and PFOA at 500 times the Danish summed criteria of 100 ng/l (for 12 PFAS) in drinking water. The contamination on that site is contained by pumping and treatment by activated carbon filters to avoid contamination of drinking water.

A 2016 study[365] reviewed the Danish Product Register for information on professional uses of PFAS from 1983 to 2016. The reported data covered 152 compounds distributed over 27 industries and showed a decline of PFAS used from 98.5 tonnes in 2003 to 13.9 tonnes in 2016. It expanded the list of uses where contamination might have occurred to include the wood industry and furniture industry; the chemical industry, iron and metal industry and rubber and plastics industry; and other locations where direct emissions may have occurred, e.g., sites of chemical/oil fires. The study recommended that investigations for possible site contamination also should be carried out at sites where these types of uses occurred.

Concerning drinking water, testing was carried out for a total of 446 samples from 318 waterworks wells from 2013 to 2018.[366] The levels for all samples were below the summed criteria of 100 ng/l for the 12 PFAS monitored in Denmark.

In 2017, the Danish Regions tested 1730 groundwater samples near potential sources of contamination for the content of the 12 PFAS in covered by the Danish drinking limit value.[367] PFAS were found above the sum criteria in approximately 10% of the samples. The groundwater samples were taken in the upper part of the water table to identify soil contamination, rather than for testing of drinking water.

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[365] Danish EPA (2016). Kortlægning af brancher der anvender PFAS.

[366] Personal communication; report not yet published (September 2018). Denmark has approximately 6,000 waterworks wells.

[367] Danish Regions (2018). Forebyggelse & samarbejde.

Sweden

According to a 2016 Swedish EPA report[368], 1,893 public water supplies were in use in 2015, 660 of which have been analysed for PFAS. About half of Sweden's public drinking water supply comes from surface water[369]; more than 80% of all surface water samples analysed contained detectable levels of PFAS. This includes sites with varying distances to identified PFAS sources. Available information concerning PFAS in groundwater is less reliable. Around 40% of the samples from areas with diffuse pollution, and 80% of samples from fire training sites contained detectable levels of PFAS.

In 2014, a survey of local authorities controlling drinking water in Sweden carried out by Swedish National Food Administration showed that around 3.6 million Swedes drink PFAS-contaminated water[370] – mainly the facilities using surface water. The levels were in most cases below 10 ng/l and were not considered to pose any threats to the public health. Also in 2014, five municipalities took actions related to their water supply in order to respond to PFAS contamination: Båstad, Ronneby, Halmstad, Uppsala and Botkyrka. Table A1.2 shows the number of sites sampled for different sources, and the analytical results.

Table A1.2: PFAS detected in areas affected by different sources of emissions

Source of PFAS	No of sites sampled		No of PFAS detected		Average levels of PFAS detected (ng/l)		Average levels of PFOS detected (ng/l)	
	SW	GW	SW	GW	SW (10 PFAS[1])	GW (7 PFAS)	SW	GW
Fire training site	214	271	18	-	3 193	43 927	1 207	24 463
Diffuse pollution	34	53	10	-	99,5	209,6	42,3	23,5
Waste facility	1	-	-	-	Not analysed for 10 PFAS	-	21,6	
Background area	60	-	14	-	13,5	-	1,5	

Note: SW = surface water.
GW = groundwater.
1) PFOS, PFOA, PFHxS, PFHxA, PFHpA, PFNA, PFDA, PFBS, 6:2 FTSA and FOSA.

The 2016 report confirmed that the presence of PFAS in water tends to increase with proximity to likely contaminated areas. Nevertheless, detectable levels are also found in background areas far from any identified sources. The same survey identified more than 2,000 potential sources from which PFAS might enter the environment; the most common types being WWTPs and major fire incidents.[371]

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[368] Swedish Environmental Protection Agency (2016). Highly fluorinated substances (PFAS) and pesticide, an overview of the presence in the environment (report in Swedish with English Summary).

[369] Swedish Water & Wastewater Association (2016). Produktion av dricksvatten.

[370] Swedish National Food Administration (2014). PFAA i råvatten och dricksvatten (report in Swedish)

[371] IVL 2016 as stated in Swedish Environmental Protection Agency (2016) report.

Table A1.3 lists the industries and activities identified as potential sources of contamination, the numbers of sites, and the estimated amount of PFAS released from each type of source into the environment.

Table A1.3: Overview of various sources of PFAS and their estimated contributions to PFAS in the Swedish environment 2016[1]

Industry/activity	No. sites identified[2]	Estimated contribution of PFAS
Production of PFAS	0	-
Production of PFAS-containing fire foam	2	Na
Waste water treatment plants (WWTP)	336	70 kg/year, of which PFOS represents 20 kg via water and 5 kg/year via sludge
Landfills (emissions from other parts of the waste treatment process are unknown)	365	70 kg/year (4 kg PFOS). 8 kg of total enters the environment; remainder enters WWTPs
Civilian airports (connected fire drilling sites)	10	1 600 kg total (380 kg PFOS) 1970–2000s
Military airports (connected fire drilling sites)	18	9 700 kg total (2 300 kg PFOS) 1970–2000s
Other fire drilling sites	295	Unknown
Fire incidents between 1998–2014 (registered by the Swedish Civil Contingencies Agency)	9,000	660 kg total (150 kg PFOS)
Chromium plating industries	11 (of which 3 use PFOS)	180 kg PFOS/year (2013, per exemption) via waste water and air
Direct emissions from other industry	Na	Na
Atmospherical deposition	Across all of Sweden	650–1 700 kg/year (25–30 kg PFOS)

Note: 2) A follow-up study in 2018 increased the number of fire incidents where AFFFs were used to 13,500 and doubled the number of other sites where AFFFs had been handled to approximately 800[3]

Source: 1) Hansson *et al.* (2016). IVL-report C 182: Sammanställning av befintlig kunskap om föroreningskällor till PFAS-ämnen i svensk miljö (report in Swedish).

3 Swedish EPA (2018). Fördjupad miljöövervakning av högfluorerade miljögifter (s.k. PFAS) och av växtskyddsmedel i vatten NV-08978-16 (report in Swedish).

Finland

Finland has recognized the use of AFFFs as a major source of dispersal of PFAS compounds. The OECD chemical safety portal[372] reports screenings of soil near airports and firefighting training centers along with screenings of drinking water.[373] The first screening in 2015 focused on military sites and use of AFFFs. It collected samples from surface (6) and ground (18) water, wastewater (5), soil samples (4) and sediment samples (3). Half of the samples contained PFCs above detection levels, with most dominant compounds being PFOS and PFOA and to a lesser extent PFBA, PFHxA AND PFHpA. The samples taken from areas where firefighting foams were used showed the highest concentrations.[374]

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[372] OECD chemical safety portal (2018). Country information for Finland.

[373] Ibid.

[374] Ryynänen T (Construction Establishment of Finnish Defence Administration) (2017). Per- and polyfluorinated substances in the Finnish Defence Forces.

Belgium (Flanders)

Flanders has undertaken stand-alone screening in order to determine the scope of contamination from PFAS in groundwater and soil. Various risk locations were identified, based on types of activities carried out in their vicinity. The activities included firefighting sites, industrial uses of PFAS (chromium plating, textile and paper manufacturers and the paint industry). A total of 24 sites were selected and 40 soil and 1 groundwater sample were tested. In 66% of the risk locations, sample concentrations were 10 times higher than the reporting limit. In 24% of the locations, concentrations were 1000 times higher than the reporting limit.[375]

The USA (national monitoring)

From 2013 to 2015, under the third Unregulated Contaminant Monitoring Rule (URCM 3), the US Environmental Protection Agency carried out testing for PFAS at a representative sample of public water systems serving less than or equal to 10,000 persons. Some 37,000 samples from 5000 public water systems were tested for PFOS, PFOA, PFNA, PFHxS, PFHpA and PFBS.[376]

A spatial analysis of the PFAS (PFOS and PFOA) found in drinking water due to the URCM 3 monitoring arrived at an estimate of six million U.S. residents served by public water supplies at levels above the US EPA's lifetime health advisory limit (70 ng/l).[377] The number of industrial sites manufacturing or using PFAS, the number of military fire training areas, and the number of wastewater treatment plants were significant predictors of the concentrations of PFAS in the public water supplies tested.

As of April 2018, at least 126 military bases in the USA reported potentially harmful levels of PFAS.[378] A total of 401 active and base closure sites had at least one area where a known or suspected release of PFAS had occurred. Starting in 2017, the US Department of Defense (DoD) has undertaken a complete monitoring of its drinking systems throughout the country.[379] As of 2018, 524 DoD water drinking systems were tested and 24 showed PFOS/PFOA levels above the US EPA lifetime health advisory levels. Monitoring of off-base private drinking systems resulted in the testing of 2,445 wells; 564 among those showed levels above the US EPA advisory levels.[380] The DoD has already spent 200 million USD studying and testing water supplies and providing either filters,

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[375] OVAM (2018). Onderzoek naar Aanwezigheid van PFAS in Grondwater, Bodem en Waterbodem ter hoogte van Risicoactiviteiten in Vlaanderen.

[376] EPA (2017). The Third Unregulated Contaminant Monitoring Rule (UCMR 3): Data Summary.

[377] Hu, X *et al.* (2016). Detection of Poly- and Perfluoroalkyl Substances (PFASs) in U.S. Drinking Water Linked to Industrial Sites, Military Fire Training Areas, and Wastewater Treatment Plants, Environmental Science & Technology Letters (10)3, pp. 344–350.

[378] Copp T, DoD: At least 126 bases report water contaminants linked to cancer, birth defects, Military Times, 26 April 2018. Accessed 01.11.2018.

[379] US Department of Defense (2017). Aqueous Film Forming Foam Report to Congress.

[380] US Department of Defense (2018) Addressing Perfluorooctane Sulfonate (PFOS) and Perfluorooctanoic Acid (PFOA).

alternate wells or bottled water where supplies were contaminated. The cost of cleaning up PFAS-contaminated water at military sites was estimated at 2 billion USD.

The US state of Michigan

In 2017, the state of Michigan set up the Michigan PFAS Action Response Team (MPART) – a multi-agency group linking health, environment and other state government agencies in an effort to investigate possible hot spots of PFAS contamination and to act to protect drinking water sources.[381] The program started after several incidents of contamination of water were discovered near military bases where AFFFs had been used as well as historic pollution at a former leather treatment factory.

The state established a health standard for PFOS and PFOA (70 ppt, the same level as the US EPA lifetime advisory standard) and tested drinking water from public water supplies and in schools across the state. At the end of August 2018, the program had tested 892 of the state's 1,841 public water systems along with schools that operated their own wells). Four public water systems were found to have problems, including the city of Flint. The state's Department of Environmental Quality looked for the source of the contamination where concentrations exceeded background levels.

Michigan is also testing effluent from 90 wastewater treatment plants, as part of a program monitoring industrial pre-treatment of wastewater. In addition, the Department of Environmental Quality is sampling for PFAS when investigating the state's Superfund sites. As of September 2018, the Michigan PFAS response website listed 34 sites where contamination had been identified.[382]

In April 2018, elevated levels of PFOS in the Flint River were linked to discharges from a plating and plastics company that had reportedly not used PFOS for years.[383] A few months later a creek that fed into the Huron River was found to have 5,500 ppt of PFOS, more than 450 times the state limit for surface water. The contamination was traced to another company[384] supplying chrome-plated plastic components to automobile manufacturers. At one time, total PFAS downstream on the Huron River tested at 56,868 ppt. Due to high levels of PFAS in fish caught in the Huron River, the state issued a "do not eat fish" advisory for 30 sq. miles of the river.

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[381] State of Michigan, Website dedicated to PFAS contamination.

[382] State of Michigan, PFAS Sites Being Investigated.

[383] No Author, Black Cloud of PFOS, The County Press, 15.04.2018.Accessed 08.11.2018.

[384] Gardner P, Astronomical' PFAS level sets new Michigan contamination milestone, Mlive , 24.09.2018. Accessed 05.11.2018.

Annex 2: Health impacts – additional information on evidence and calculations

This annex presents additional information regarding the health assessments.

Part 1 explains the calculations for each monetised health impact in more detail as well as the country-specific estimates.

Part 2 presents an overview of the key epidemiological studies drawn upon for the assessment. It provides information about the region and population studied, the PFAS compounds in the contamination, the relevant health endpoint, the time period and the sample size. For example, the first study mentioned (Mastrantonio *et al.*, 2017) was used for the calculation of health impacts among the population with elevated exposure through close residence to a chemical plant and AFFFs contamination.

Upon request the excelspread sheets used for the monetarisation and valuation in this report can also be provided along with a guidance on how to use the estimation of costs for value transfer.

Part 1: Estimating health impacts in exposed populations

This section explains the calculations underpinning each of the quantitative estimates presented in Section 5.1.

Occupational (high) exposure scenario

The estimation for the occupational exposure scenario relied on a number of parameters and assumptions, which are listed below:

- assume that the number of PFAS-producing plants in the EEA ranges from 12 to 20 (Case Study 1);
- assume there are 352,764 small manufacturing plants and 780 large manufacturing plants across the EEA in the categories of manufacturing and commercial uses identified in Case Study 2 (textiles, leather, metal plating, paper and paper products, paints and varnishes, soaps and detergents, plastics and resins, car wash establishments);
- assume that the number of employees (exposed population) in small manufacturing plants is on average 30 while the number of employees in large plants is on average 300;

- assume that an estimated 3% to 10% of the types of manufacturing plants identified in Case Study 2 use PFAS-treated products; and
- the elevated risk of death due to kidney cancer from occupational exposure to PFOA (relative risk = 3.67). This estimate was obtained from an epidemiological study carried out in West Virginia.[385] The elevated risk was assumed to apply to the exposed population in the Nordic and EEA countries.

The calculation began with an estimation of the exposed population of workers in the Nordic countries and the EEA using information from the first three assumptions. Table A2.1 presents the results.

Table A2.1: Estimating the size of the population with occupational exposure to PFAS

	Best estimate	Assumption for calculation	Ave. workers in each	Nordic*	EEA*	Estimated exposed population
PFAS plants	12–20	Assume upper estimate	500	-	✓	10,000
Manufacturing plants – small	352,764	Assume that 3–10% have PFAS treated products	30	✓	✓	31,749–105,829
Manufacturing plants – large	780		300	✓	✓	702–2,340
Total:						334,508–1,091,692

Note: *The actual numbers are not known and therefore a best guess was made to support the calculation.

We considered the death rate in this population which might be attributed to kidney cancer due to PFAS exposure. The number of deaths was estimated and compared with a scenario where occupational PFAS exposure was not present. This calculation relied on the third parameter from Steenland and Woskie, 2012. The elevated risk of kidney cancer mortality was evident for a quartile of the exposed population. Similarly, the calculation for this study assumed that the only a quarter of the population with occupational exposure faced a higher risk of kidney cancer due to PFAS exposure.

Table A2.2 presents the calculation for the Nordic and EEA countries together. The lower bound is based on the assumption that 3% of selected manufacturing plants make PFAS-treated products while the upper bound uses the assumption of 10%. These assumptions were made due to the absence of actual figures.

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[385] Steenland K and Woskie S (2012). Cohort mortality study of workers exposed to perfluorooctanoic acid. American journal of epidemiology. 176(10) pp.909–917.

Table A2.2: Calculation of monetised impact of elevated mortality from kidney cancer due to occupational PFAS exposure – EEA countries

	Lower bound	Upper bound	Explanation/source
Exposed population	334,508	1,091,692	See Table A2.1 above
Population that experiences elevated health risk	83,627	272,923	Assumes only a quartile of the exposed population experiences an elevated risk of kidney cancer mortality
General population death rate by kidney cancer	0.01%	0.01%	Eurostat, 2015 standardised death rate
Annual deaths in exposed population - baseline	4.98	16.27	Milieu calculations using the elevated risk information from (Steenland and Woskie, 2012).
Not linked to PFAS exposure:	1.4	4.4	
Linked to PFAS exposure:	3.6	11.8	
Total value per year	EUR 12.7 million	EUR 41.4 million	Milieu calculations using ECHA lower bound value of life (EUR 3.5 million)

Elevated (medium) exposure scenario

Three calculations were made for the scenario. The first was related to the costs of the elevated risk of all-cause mortality among adults. The second was an estimation of the number of births of low birth weight. The third was related to the higher risk of common childhood infections among children (immunotoxicity endpoint). Each is described below.

The estimation for the elevated risk of all-cause mortality drew on two key sources of information. One was an epidemiological study from the Veneto region.[386] Another was an estimate from Sweden on the human exposure to elevated levels of PFAS in groundwater. The key assumptions were:

- a relative risk of all-cause mortality due to elevated PFAS exposure. For this, we relied on an estimate from an epidemiological study carried out in the Veneto Region.[387] The study found a relative risk of 1.11 and a 95% confidence interval of 1.10 to 1.12. The calculation assumes that the elevated risk found in the Veneto Region applies to the exposed population in the Nordic and EEA countries;
- up to 300,000 residents of Sweden (or about 3%) are exposed to source levels of PFAS above the limit value via municipal drinking water.[388] The calculation assumes that the level of exposure in Sweden is equivalent across the Nordic countries and the EEA.

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[386] Mastrantonio M *et al.* (2017). Drinking water contamination from perfluoroalkyl substances (PFAS): an ecological mortality study in the Veneto Region, Italy. The European Journal of Public Health. Feb 1;28(1):180–185.

[387] Ibid.

[388] Holmström *et al.* (2014). Nationell screening av perfluorerade föroreningar (PFAA) i dricksvatten. Rapport no 2014/20 (In Swedish).

Table A2.3 presents the calculation. The lower and upper bounds are based on the values of the 95% confidence interval from the estimate from Mastrantonio *et al.*, 2017.

Table A2.3: Calculation of annual monetised impact of elevated mortality due to elevated PFAS exposure – Nordic and EEA countries

	Nordic countries		EEA countries		Explanation/source
Total population	20,698,030		415,697,178		Population ages 19 years and up (Eurostat, 2017)
Population with elevated exposure	620,941		12,470,915		3% parameter estimate applied
General mortality rate	1.0%				Eurostat, 2017
Annual deaths in exposed population - baseline	6,458		129,199		Milieu calculations using the elevated risk information from Mastrantonio *et al.*, 2017.
	Lower bound	Upper bound	Lower bound	Upper bound	
Not linked to PFAS exposure:	5,871	5,766	117,453	115,356	
Linked to PFAS exposure:	587	692	11,745	13,843	
Total value per year	*EUR 2.1 billion*	*EUR 2.4 billion*	*EUR 41.1 billion*	*EUR 48.5 billion*	*Milieu calculations using ECHA lower bound value of life (EUR 3.5 million)*

The estimation for the elevated risk of low birth weight drew on three sources of information:

- number of total live births and percentage of low birth weight by country (Eurostat);
- elevated risk of low birth weight due to PFAS exposure. The calculation assumed that an estimate from an epidemiological study could be extrapolated to the exposed population in the Nordic and EEA countries. The study found a relative risk of low birth weight of 1.50[389];
- population exposure to elevated levels of PFAS, estimated to be 3%.[390] This parameter was also used in the previous calculation. The calculation assumes that the level of exposure in Sweden is equivalent across the Nordic countries and the EEA.

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[389] Stein C R *et al.* (2009). Serum levels of perfluorooctanoic acid and perfluorooctane sulfonate and pregnancy outcome. American journal of epidemiology, 170(7), pp.837–846.

[390] Holmström *et al.* (2014). Nationell screening av perfluorerade föroreningar (PFAA) i dricksvatten. Rapport no 2014/20 (In Swedish).

Table A2.4 presents the calculation.

Table A2.4: Calculation of births of low birth weight due to elevated PFAS exposure – Nordic and EEA countries

	Nordic countries	EEA countries	Explanation/source
Number of births per year	294,777	5,211,464	Eurostat, 2016
Births with elevated exposure	8,843	156,344	3% parameter estimate applied
Low birth weight rate	4.6 %	6.8 %	Eurostat, 2017
Annual low birth weight in exposed population - baseline	407	10,631	Milieu calculations using the elevated risk information from Stein *et al.*, 2009.
Not linked to PFAS exposure:	271	7,088	
Linked to PFAS exposure:	136	3,544	

The estimation for the elevated risk of fever is based on findings from a study from Denmark.[391] The study found that children ages 1–4 years of age with the highest serum concentration of PFAS (10.19–25.10 ng/ml) had an increased risk of fever. This serum concentration level most closely corresponds with the elevated exposure scenario. The calculation assumed that all children aged 1–4 years with an elevated exposure would face an increased risk of fever. The key pieces of information and assumptions were as follows;

- number of children ages 1–4 years of age in the Nordic countries and the EEA (Eurostat);
- elevated risk of infection. The calculation relies on the aforementioned Danish study, which finds a relative risk of fever of 1.65.[392] The calculation assumes that the elevated risk of additional days with fever found in the study from Denmark applies to the entire population at elevated exposure in the Nordic countries and the EEA;
- population exposure to elevated levels of PFAS, estimated to be 3%.[393] This parameter was also used in the two previous calculations. The calculation assumes that the level of exposure in Sweden is equivalent across the Nordic countries and the EEA.

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[391] Dalsager L *et al.* (2016). Association between prenatal exposure to perfluorinated compounds and symptoms of infections at age 1–4years among 359 children in the Odense Child Cohort. Environment international, 96, pp.58–64.

[392] Ibid.

[393] Holmström *et al.* (2014). Nationell screening av perfluorerade föroreningar (PFAA) i dricksvatten. Rapport no 2014/20 (In Swedish).

Table A2.5 presents the calculation.

Table A2.5: Calculation of additional days of fever among children 1–4 years old – Nordic and EEA countries

	Nordic countries	EEA countries	Explanation/source
Number of children ages 1–4 years	1,507,631	26,159,812	Eurostat, 2016
Children with elevated exposure	45,229	784,794	3% parameter estimate applied
Fever days per year in baseline	4.7 days	4.7 days	Eurostat, 2017
Fever days in exposed population	212,576	3,688,533	Milieu calculations using the elevated risk information from Dalsager *et al.*, 2016.
Not linked to PFAS exposure:	128,834	2,235,475	
Linked to PFAS exposure:	83,742	1,453,059	

Background (low) exposure scenario

The estimation of health impacts from background exposure to PFAS focused on the health endpoint of hypertension. It drew on epidemiological evidence gathered from the National Health and Nutrition Examination Survey in the United States, which focused on the adult population.[394] The parameters and assumptions in the calculation include the following:

- the adult population in the Nordic countries and the EEA (Eurostat);
- the incidence rate of hypertension in the EU[395];
- elevated risk of hypertension. The calculation relies on an estimate for the elevated risk of hypertension due to PFAS exposure.[396] The study found an odds ratio of 1.63 and a 95% confidence interval of 1.2 to 2.2;
- elevated risk of death due to hypertension. The calculation relies on an estimate from Zhou *et al.*, 2018.

Min *et al.*, 2012 find an increased risk of hypertension in half of the population. The calculation assumes that half of the exposed population in the Nordic countries and the EEA face an elevated risk of hypertension. Table A2.6 show figures from calculations of the monetised impact of elevated risk of hypertension due to background exposure to PFAS for the Nordic and EEA countries.

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[394] Min, J. Y. *et al.* (2012). Perfluorooctanoic acid exposure is associated with elevated homocysteine and hypertension in US adults. Occup Environ Med, 69(9):658–62.

[395] European Heart Network (2017). European Cardiovascular Disease Statistics 2017.

[396] Ibid.

Table A2.6: Calculation of monetised impact of elevated risk of hypertension due to background exposure to PFAS – Nordic and EEA countries

	Nordic countries		EEA countries		Explanation/source
Exposed population	20,698,030		415,697,178		Adult population (19 years and up), Eurostat, 2017
Population at higher risk	10,349,015		207,848,589		About half have an increased risk of hypertension (Min *et al.*, 2012).
Incidence rate of hypertension	0.01				European Cardiovascular Disease Statistics, 2017
Number of new hypertension cases	75,931		1,525,000		Milieu calculations using the elevated risk information from Min *et al.*, 2012.
	Lower bound	Upper bound	Lower bound	Upper bound	
Elevated risk of hypertension due to PFAS exposure	1.2	2.2	1.2	2.2	
Not linked to PFAS exposure:	63,276	34,514	1,270,833	693,182	
Linked to PFAS exposure:	12,655	41,417	254,167	831,818	
Elevated risk of disease due to hypertension	0.012				Zhou *et al.*, 2018
Number of deaths	916		18,398		Milieu calculations using the elevated risk information from Zhou *et al.*, 2018.
Not linked to PFAS exposure:	763	416	15,331	8,363	
Linked to PFAS exposure:	153	500	3,066	10,035	
	EUR 0.7 billion	EUR 2.2 billion	EUR 10.7 billion	EUR 35 billion	Milieu calculations using ECHA lower bound value of life (EUR 3.5 million)

Part 2: Key epidemiological studies

An overview of the epidemilogical studies reviewed in this report is presented in Table A2.7.

Table A2.7: Overview of epidemiological studies reviewed

Study	Population	PFAS Compound	Health endpoint	Time period	Sample size
Mastrantonio *et al.*, 2017	Veneto Region	PFOA, PFOS, PFHxS	Mortality	1980–2013	41,841 deaths; 143 605 residents in contaminated area; 588 012 residents in uncontaminated areas
Vieira *et al.*, 2013	C8 Health Project	PFOA	Cancer	1996–2005	29,118 cases of cancer; resident population over 500,000
Steenland *et al.*, 2010	C8 Health Project	PFOA, PFOS	Uric acid	2005–2006	54,951 adults
Barry *et al.*, 2013	C8 Health Project	PFOA	Cancer	2005–2006	32,254 adults; 3,589 cancer cases
Steenland *et al.*, 2009	C8 Health Project	PFOA, PFOS	Serum lipids	2005–2006	46,294 adults
Byrne *et al.*, 2018	St Lawrence Island, Alaska	PFOA, PFOS, PFUnA, PFNA	Thyroid hormone	2013–2014	85 adults
Min *et al.*, 2012	USA - background levels	PFOA	Hypertension	2003–2006	2,934 adults
Nelson *et al.*, 2010	USA - background levels	PFOA, PFOS, PFHxS, PFNA	Cholesterol	2003–2004	860 individuals
Bonefeld-Jorgensen *et al.*, 2011	Greenland	PFOA, PFOS	Breast cancer	2000–2003	31 breast cancer cases and 115 controls
Simpson *et al.*, 2013	C8 Health Project	PFOA	Stroke	2005–2006	32,254 individuals aged 12 years and above
Winquist and Steenland, 2014	C8 Health Project	PFOA	Hypertension and cholesterol	2005–2006	32,254 individuals aged 12 years and above
Steenland *et al.*, 2013	C8 Health Project	PFOA	Ulcerative colitis	2005–2011	32,254 individuals aged 12 years and above
Bonefeld-Jorgensen *et al.*, 2011	Greenland	PFOA, PFOS, PFHxS, PFNA, PFOSA	Breast cancer	1996–2002	250 breast control cases and 233 controls
Steenland and Woskie, 2012	C8 Health Project - workers	PFOA	Mortality	1952–2008	1,308 workers; 243 deaths
Brede *et al.*, 2010	Arnsberg, Germany	PFOA	None	2008	138 individuals
Jensen *et al.*, 2015	Denmark	PFOA, PFOS, PFNA, PFDA	Miscarriage	2010–2012	2,874 in relatively exposed area and 336 in a relatively unexposed area
Shankar *et al.*, 2012	USA - background levels	PFOA	Cardiovascular disease	1999–2003	1, 216 adults
Alexander *et al.*, 2003	Decatur, Alabama (USA)	PFOS	Mortality; Bladder cancer	1998	2,083 individuals; 145 deaths
Bach *et al.*, 2016	Denmark	PFOA, PFOS, PFHxS, PFUnA, PFNA, PFHpS, PFDA	Birth weight	2008–2013	1,507 mother-child dyads
Wang *et al.*, 2016	Taiwan	PFOA, PFUnA, PFNA, PDFeA, PFUnDA, PFDoDA	Fetal and post-natal growth	2000–2001	223 mother-child dyads
Yang *et al.*, 2016	Beijing, China	PFOA, PFOS, PFUnA, PFNA, PFDA	Thyroid hormones	2013	157 mother-child dyads
Ingelido *et al.*, 2018	Veneto Region	PFOA, PFOS	None	2015–2016	507 subjects, 257 in high exposure areas

Annex 3: Data used for environment-related cost calculations

This annex presents the data used and the calculations carried out for the environment-related cost estimates in three parts:

- Part 1: The costs gathered via the case studies and additional research;
- Part 2: Data used in the aggregation of costs as presented in Section 5.2 of the study;
- Part 3: Full cost estimates by country.

Upon request the excelspread sheets used for the monetarisation and valuation in this report can also be provided along with a guidance on how to use the estimation of costs for value transfer.

Part 1: The costs gathered via the case studies and additional research

This Annex reports the data collected for the following cost elements:

1. Monitoring to assess PFAS contamination where it is suspected (Table A3.2 and Table A3.3).
2. Provision of a temporary uncontaminated drinking water supply (Table A3.4).
3. Upgrading of water treatment works and ongoing costs for maintenance and replacement and disposal of filters (Table A3.5).
4. Excavation and treatment of soils (Table A3.6).
5. Health assessments where contamination is found (Table A3.7).

Exchange rates used

All currency data have been converted to Euro in 2017 prices. The exchange rates used are based on Purchasing Power Parity (PPP), from OECD. Purchasing power parities are the rates of currency conversion that equalise the purchasing power of different currencies by eliminating the differences in price levels between countries. In their simplest form, PPPs show the ratio of prices in national currencies of the same good or service in different countries. PPPs are also calculated for groups of products and for each of the various levels of aggregation up to and including GDP. The basket of goods and services priced is a sample of all those that are a part of final expenditure: household consumption, government services, capital formation and net exports, covered by GDP. The original indicator is measured in terms of national currency per US dollar. It will be noted that there is variation between PPP rates and market exchange rates. Inflation has been accounted for using the HICP indicator from Eurostat. Key data for currency conversion to 2017 EUR are given in Table A3.1. All costs that follow in the tables, etc. presented in the report have been updated to 2017 EUR.

Table A3.1: Conversion rates used

	EU28 HICP price index, 2015=100	EUR/Danish Krone	EUR/Norwegian Krone	EUR/Swedish Krona	EUR/USD	EUR/GBP
2008	89.82	0.0995	0.0892	0.0900	0.7904	1.1254
2009	90.71	0.0984	0.0838	0.0853	0.7609	1.0718
2010	92.60	0.1008	0.0836	0.0848	0.7644	1.0883
2011	95.47	0.1010	0.0830	0.0853	0.7543	1.0680
2012	97.99	0.0999	0.0836	0.0873	0.7556	1.0769
2013	99.47	0.0999	0.0813	0.0854	0.7345	1.0561
2014	100.01	0.1006	0.0794	0.0845	0.7370	1.0559
2015	100.00	0.1031	0.0776	0.0844	0.7551	1.0832
2016	100.25	0.1000	0.0727	0.0811	0.7360	1.0484
2017	101.97	0.1005	0.0715	0.0799	0.7274	1.0196

Source: PPP conversion rates: OECD, https://data.oecd.org/conversion/purchasing-power-parities-ppp.htm

Harmonised Index of Consumer Prices: Eurostat, https://ec.europa.eu/eurostat/web/hicp/data/database

Monitoring to assess PFAS contamination where it is suspected

Data identified so far for monitoring costs, in most cases relating to early site investigations, are shown in Table A3.2 and Table A3.3 for Europe and the USA. The annual sampling cost cited for Ronneby Airport is a figure for the period after site investigation and remediation, and is understood to possibly persist for many years. For most sites considered, the total costs of monitoring alone are in excess of EUR 100,000, and in several cases exceed EUR 1 million. Only partial estimates of cost have been identified for some sites.

Table A3.2: Costs for PFAS monitoring, European data

Location	Sampling	Cost
Arlanda Airport	Sampling of groundwater, annual cost, to 2016	EUR 5,200
	Annual cost for site investigations, 2017–2022	EUR 8,000
Baden-Wurttemberg	Investigation and research following identification of PFAS contamination	EUR 6.1 million
Bromma Airport	Sampling and consultant costs for area where contamination was found	EUR 32,000
Dusseldorf (fire at bottle depot)	Total cost of assessment	EUR 1.2 million
Kallinge Airport	Additional cost for water sampling within the monitoring programme	EUR 4,000
Kiruna Airport	Investigation of a confined potential soil contamination	EUR 8,100
	Estimated cost for implementing action plan, including: identifying risk objects, technical soil and water investigation, assessment of risks and need for measures, etc.	EUR 1.6 million
Norwegian coastline	Annual costs for analysis only, does not include sampling and reporting	EUR 36,000
Oslo fjord		EUR 21,000
Atmospheric contaminants (Norway)		EUR 32,000
Screening of emerging contaminants (Norway)		EUR 36,000
Riverine inputs and direct discharges to Norwegian coastal waters		EUR 4,000
Contaminants in Norwegian lakes		EUR 14,000
Pollutants in the Norwegian terrestrial and urban environment		EUR 28,000
Ronneby Airport	Annual sampling cost after investigation and remediation	EUR 3,400
Stadtwerke Rastatt	Measuring groundwater wells in WSG Ottersdorf	EUR 440,000
Stadtwerke Rastatt	Measuring groundwater wells (WSG Rauental)	EUR 110,000
Umeå Airport	Sampling and investigation	EUR 110,000
Uppsala	Future annual additional costs to investigate potential PFAS-sources	EUR 16,000 to EUR 56,000
Tyrifjorden	Field sampling	EUR 11,000
	Additional sampling of sediments, incl. reporting	EUR 3,600
	Admin, coordination fieldwork	EUR 720
	Analyses	EUR 13,000
	Analyses of additional sediment samples	EUR 3,600
	Reporting	EUR 11,000
	Budgeted future cost, fieldwork, analysis, reporting, admin	EUR 140,000
Uppsala	Sampling associated with contaminated water supply Average cost for 2012–2014 Average cost for 2015–2017	EUR 44,000 EUR 160,000

Table A3.3: Costs for PFAS monitoring, US data

Sampling		No. samples	Cost	Cost/sample
Washington State, USA	Monitoring	500	EUR 170,000	EUR 402
	Monitoring	8,000	EUR 1,900,000	EUR 278
	Monitoring	24,000	EUR 5,800,000	EUR 285
US Military sites	Additional testing e.g. of specific incidents		EUR 2,200,000	

For the US data, the sampling regime under these different options includes costs of sample analysis and staff time to oversee testing and assist communities with drinking water contamination. Washington State foresees a need to monitor all public water supplies, down to *Group B public water systems with fewer than 15 connections and fewer than 25 people per day*.

Provision of a temporary uncontaminated drinking water supply

The only information obtained so far on the costs of supplying water temporarily is from the USA (Table A3.4). A widely reported figure of USD 10 million for provision of a temporary filtration system at Hoosick Falls, New York State and investigation into an alternative drinking water source is of a similar magnitude to the costs reported elsewhere for permanent systems. This suggests that the responsible authorities are seeking an alternative source with no contamination (as has been done at Bennington, just across the State border in Vermont), but that this will take several years to come online, essentially meaning that there is no difference between what is defined as a "temporary" solution for Hoosick Falls and permanent solutions elsewhere.

Another figure is available for the rental of two large filtration tanks at Hoosick Falls at a cost of USD 300,000.[397] It is unclear how this temporary installation differs to anything more permanent. A further temporary measure involved provision of free bottled water for collection from local supermarkets though there are no data available on the costs of this for Hoosick Falls. However, contamination at Peterson, Colorado, led to bottled water being provided. Costs for this are given as EUR 81,000, though it is unclear how many people were provided with the water which was intended specifically for residents using private wells or small drinking water systems.[398] The total population in the area of concern is given as 60,000, of which it is estimated that 10–15,000 received water at levels above the health advisory threshold.[399] Considering the likely costs of providing water per head, it seems likely that group served by the EUR 81,000 fund for bottled water was only a very small part of the 10–15,000 in the zone of highest concern.

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[397] DeMasi M, Hoosick Falls water filtration still weeks away, Albany Business Review, Jan 29, 2016. Accessed 05.08.2018.

[398] KRRC (2016). Air Force Signs Contract for Bottled Water Distribution.

[399] KRRC (2016). Health & Water Officials Try to Reassure Residents in Areas of PFC Contamination.

Table A3.4: Costs normalised against population for temporary improvements to water systems

Site	Action	Population	Cost	Cost/head
Hoosick Falls	Provision of bottled water	3,400	No data	
Peterson, Colorado	Provision of bottled water		EUR 81,000	
Temporary filtration system (1)				
Hoosick Falls	Installation of temporary filters	3,400	EUR 270,000	EUR 79
Temporary water filtration system (2)				
Hoosick Falls	Temporary water filtration system and investigation into an alternative drinking water source	3,400	EUR 8.6 million	EUR 2,500

Press reports from Hoosick Falls indicate that when water supplies are declared clear of contamination there is still mistrust, with some people preferring to carry on drinking bottled water.[400] Irrespective of the rationality behind the decisions made by individuals, this will also represent a social cost.

Upgrading of water treatment works and ongoing costs for maintenance and replacement and disposal of filters

Table A3.5 show costs normalised against population for improvements to water treatment in response to PFAS contamination, in cases where some reasonable estimate of the human population affected can be made. Cost data are also presented where no estimate of population is possible, for completeness. Within the table, categories of cost are grouped, starting with installation of advanced filters. Each group shows economies of scale, with cost/head reducing as the population served increases, as would be expected.

A general problem with the cost data lies in understanding what elements of cost are covered. For example, the cost given for upgrading a WWTP may cover the capital costs of plant upgrade and subsequent maintenance costs, or the capital costs alone. In some cases costs are reported as being inclusive or exclusive of VAT, whilst in others no comment is provided. It is also often unclear whether maintenance costs, when provided, are represented as additional annual maintenance costs, or total maintenance costs. In some cases the cost data are separated out so that it is (reasonably) clear what is covered. In others, costs are reported as total but without further explanation. Where possible, original sources have been consulted in order to understand the data better.

Estimates of the population served by each plant are approximate, based on the population of the nearest town or city. This introduces potentially significant error: for example, the low cost relative to size (EUR 8/person) for Dusseldorf may result from exaggeration of the population served. The issue is also highlighted in the case of Bennington (USA), for which two estimates of the cost per head for installation of new pipework to connect homes to an alternative water source are possible (not included in the table). The

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[400] Ward C, Hoosick Falls free bottled water program comes to an end.News10 (01 September 2017). Accessed 18.10.2018.

total cost of this action is given as USD 20 million[401] (EUR 17 million). To derive a low estimate of damage per head, we divide by the total population of Bennington, 15,764, and reach a figure of EUR 1,085 per person. However, Saint-Gobain, the company funding the work as it is linked to a factory that they were responsible for, state that they have provided connection to 200 homes. Assuming an average occupancy rate of 2.5 people per home gives a total population 500. Dividing the USD 20 million cost of the work by this much lower population drives cost per head up to EUR 34,000 (and per property to EUR 85,000).

With respect to variation in estimates, a Swedish expert who has worked on PFAS issues at a number of airports[402] risk assessment and investigating measures might vary between SEK 5–15 million, remediating individual water bodies for drinking water abstraction could cost between SEK 0–15 million, and other measures to remediate the site could be estimated to SEK 20–50 million. Likewise, Avinor in Norway estimated that remediation might cost between NOK 3–30 million per airport.[403]

Accepting these uncertainties, the dataset provides reasonable ranges for feeding into the analysis. As before, the dataset may be improved by researching the costs of improved water treatment without specific reference to PFAS.

An issue for aggregation of results concerns the size of communities affected. Clearly, not all will be very small or very large or average. This may best be addressed through sensitivity analysis.

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[401] VPR News, Bennington Homes Contaminated With PFOA Connect To Clean Municipal System.

[402] Personal communication from Niklas Löwegren, Project leader contaminated sites, Swedish Transport Agency.

[403] Heggelund, A.(2017) Norwegian EPA, personal communication September 2018.

Table A3.5: Costs for upgrading water treatment works, by activity

Incident	Description	Population [1]	Cost	Cost/person
Installation of filters				
Europe				
Arlanda	Estimated cost of new treatment plant for surface water leaving site preventing contamination of Lake Malaren, used for drinking water		EUR 180,000	
Dusseldorf	Total cost of managing PFC in the contaminated drinking water	1,200,000	>EUR 13,000,000	>EUR 10
	Costs of remediation after AFFF use		>EUR 12,000,000	> EUR 8
	Total costs of remediation		>EUR 100,000,000	> EUR 80
Kallinge(SE)	Installation of new pipelines, filters	4,561	EUR 4,300,000	EUR 943
Landvetter	Operation (2016) and installation of new (2017) treatment plant for surface water		EUR 250,000	
Malmo	Establishing water treatment facility and analysing water		EUR 140,000	
	Cost of treatment facility, sampling and dike cleansing		EUR 110,000	
	Estimated cost for future remediation and monitoring in surrounding recipients		EUR 100,000	
Stadtwerke Rastatt	Rauental water works		EUR4,000,000	
Veneto	Installation of filters	120,000	EUR 2,100,000	EUR 18
USA				
Brunswick County	Upgrade treatment plant with activated carbon	107,000	EUR 72,000,000	EUR 673
Cape Fear	Upgrade treatment plant with granular activated carbon (Cape Fear)	360,000	EUR 33,000,000	EUR 92
Cape Fear River	Upgrading of treatment plant installation of reverse-osmosis system (Brunswick County)	107,000	EUR 72,000,000	EUR 672
Cape Fear River	Expansion of additional treatment works		EUR 28,000,000	
Hoosick Falls (NY)	"Temporary" water filtration system	3,400	EUR 7,400,000	EUR 2,200
Issaquah	Installation of water treatment systems	30,234	EUR 880,000	EUR 29
Moose Creek	Installation of granular activated carbon system	9,000	EUR 2,700,000	EUR 300
Peterson Air Force base	Contamination from AFFFs, installation of water treatment systems for known contaminated wells	60,000	EUR 3,300,000	EUR 55
Tennessee River (Decatur)	Installation of carbon filtration systems	55,000	EUR 3,700,000	EUR 67
Warrington	Installation of carbon filtration systems	23,000	EUR 12,000,000	EUR 522
Temporary water filtration system				
USA				
Hoosick Falls	Temporary water filtration system	3,400	EUR 270,000	EUR 79
Annual maintenance cost of water treatment works				
Europe				
Landvetter	Annual operating cost		EUR 40,000	
Stadtwerke Rastatt	Rauental water works	25,000 (50% of Rastatt)	EUR 750,000	EUR 30

Incident	Description	Population [1]	Cost	Cost/person
Uppsaala	Annual cost for activated charcoal filtration, 2012 2014–2017 average		EUR 30,000 EUR 110,000	
Veneto	Annual operating cost	120,000	EUR 920,000	EUR 8
USA				
Moose Creek	Annual maintenance cost	9,000	EUR 230,000	EUR 26
Tennessee River (Decatur)	Annual maintenance cost	55,000	EUR 550,000	EUR 10
Rebuilding of water treatment works				
Europe				
Stadtwerke Rastatt	Ottersdorf water works	25,000 (50% of Rastatt)	EUR 3,900,000	
Uppsaala	Reconstruction of treatment plant to deal with PFAS		EUR 260,000	
Install new pipelines / connections				
Europe				
Jersey [2]	Connection to water supplies	161	EUR 210,000	EUR 1,306
Jersey [2]	Jersey Water Mains connection costs	161	EUR 810,000	EUR 5,037
Kallinge	Installation of new pipelines, filters	4,561	EUR 6,650,000	EUR 1,458
Kallinge	Costs of providing alternative water supply via new pipe connections between 2013 and 2015 and use of a new set of carbon filters	4,561	EUR 4,300,000	EUR 943
Stadtwerke Rastatt	Water pipe between water works at Muggensturm and Rauental Water pipe Rauental-Lochfeldstr	49,100	EUR 900,000 EUR 910,000	EUR37 accounting for both pipelines
Veneto	Installation of new pipelines (not carried out)	120,000	EUR 61,700,000	EUR 514
Other costs				
Europe				
Buncefield UK	Lost opportunity cost from closure of a borehole		EUR 2,600,000	
Jersey [2]	Site investigation	161	EUR 1,430,000	EUR 8,893
Jersey [2]	Remedial works to old fire ground	161	EUR 450,000	EUR 2,799
Jersey [2]	Fees, etc.	161	EUR 910,000	EUR 5,659
Jersey [2]	Capital works on Fire Training Ground	161	EUR 6,300,000	EUR 39,179
Uppsaala	Risk analyses and planning of measures to safeguard Uppsala's drinking water from pollution (not only PFAS)		EUR 320,000	
	Time spent within the public water authority (2012–2017, average annual cost)		EUR 55,000	

Note: 1)Population estimates provided here are for the municipalities identified in the case studies and hence are not necessarily specific to the number of people served by water treatment works. There may be significant uncertainty in these figures, especially for the largest towns and cities included.

2)The Jersey Airport case provides a breakdown of cost elements, as shown. It is possible that these costs are included in other estimates, but without disaggregation.

Excavation and treatment of soils

Costs relating to environmental remediation, mostly in relation to soil cleaning but including some groundwater cleaning also, are presented in Table A3.6.

Table A3.6: Costs related to remediation of environment, after contamination from PFAS due the different sources

Incident	Year[1]	Description	Cost (EUR)[2]
European cases			
Arlanda Airport (SE)	2016	Cost of testing soil clean-up	EUR 7,600
	Future	Est. cost of pilot study on remediation costs	EUR 80,000 to EUR 400,000
	Future	Estimated costs of remediation	EUR 800,000
Clean up of agricultural fields in Baden-Wurttemberg (DE)	Future	Estimate of changing contaminated soil	Up to EUR 3 billion
Bromma Airport (SE)	Future	Estimated future remediation costs	EUR 340,000
Copenhagen Airport	2016	Clean-up of site and reconstruction of fire training area	EUR 15 million
Contamination due to Dusseldorf Airport (DE) Population = 1.2 million urban area	2014	Cost of 3 wells controlling the point sources: Estimated total remediation cost, up to:	EUR 2 million EUR 100 million
Contamination around Jersey Airport (UK) Population affected = 67 properties	1993	Estimated total remediation cost	7.08 million
Contamination around Nurnberg Airport (DE)[3]	NA	Initial budget set by Nurnberg Airport for PFAS remediation	EUR 10,000,000
Contamination around Oslo Airport (NO)[4]	NA	Removal of 0.6 kg PFAS from stony area Removal of 0.5 kg PFOS/year by treatment facility at fire drill sites	EUR 1.9 million EUR 2.2 million
Contaminated soils, Schiphol (NL)	2008	Removal of 50,000 m^3 of soil, 143 kg PFOS	EUR 30–40 million
Visby Airport (SE)	Future	Estimated future remediation costs	EUR 800,000 to EUR 1.4 million
US cases			
Minnesota contamination due to 3M factory disposal sites (US) [5]	2002	Total cost for 10 years for treatment of surface/ground water, sediment and soil at 3 sites	EUR 36 million
Contamination in Warrington due to use of AFFFs (US)	2016	Estimation of total costs for environmental restoration	EUR 77.7 million

Note: 1) Year might refer to year of detection, or the year costs were incurred.
2) Costs in other currencies are converted to Euro, using average annual rates for the year they incurred.
3) Weber R, (2016). Presentation for Science and Policy of Organohalogens pre-Dioxin Symposium, accessed August 2018.
4) Norwegian Environment Agency (2016). PFAS-forurensning i grunnen Oppsummering fra workshop 26. Rapport M-622.
5) Legal settlement presented in table 19.

The costs of dealing specifically with contaminated soils reported in Table A3.6 equate to the following estimates per unit of material (for those sites where data on both costs and quantity of PFAS were available):

- Nurnberg Airport: EUR 100,000/kg mixed PFOS, PFHxS, PFBS
- Schiphol Airport: EUR 200,000–280,000/kg PFOS; EUR 600–800/m^3 soil
- Oslo Airport: EUR 2.1 to EUR4.3 million/kg PFOS

Variability in the range is not surprising given that the costs for soil remediation are a function of several factors, including[404]:

- the quantity of PFAS that was spilled or emitted;
- the presence of other contaminants that need to be eliminated;
- the quantity of soil that has been contaminated;
- the type of soil and its qualities for retaining PFAS;
- variability in the use of sites and surrounding lands and waterbodies that will influence the desired level of remediation.

Three Norwegian airports have modelled the costs of PFAS removal (including both water and soil), using different combinations of methods and different levels of allowed remaining concentrations. For Kristiansand airport, the figures range from around NOK 29.5 to NOK 332.5 million (EUR 2,1–24 million); from NOK 6.3 to NOK 91.3 million (EUR 0.5–7.1 million) for Harstad/Narvik; and from NOK 5.7 to NOK 113.4 million (EUR 0.4–8.1 million) for Svalbard Longyearbyen. Due to the highly hypothetical nature of these cost figures, as well as the vast number of cost estimates generated by the various choices of method and target concentration, they have not been included into the cost tables presented above. For the full details of the cost of the various remediation scenarios, the reader should consult the original reports.[405]

Health assessments where contamination is found

A final category of cost concerns health assessment of the population in cases where contamination above permitted levels is identified. This category of cost is accounted for here, rather than in the section on "health costs", as associated costs relate to management of the problem rather than the health or environmental damage caused.

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[404] National Research Council (1997). Innovations in Ground Water and Soil Cleanup: From Concept to Commercialization. Chapter 6. National Academy Press. Chapter 6.

[405] Avinor (2018). PFOS I Focus, (In Norwegian) Accessed 05.09.2018.

For the Veneto Region, WHO provides the following information on a human biomonitoring study of the affected population:

- Dates: From July 2015 to April 2016
- Population: Exposed and unexposed population
- Lead organisations: National Institute of Health, the Regional Environmental Protection Agency and health care trusts in the areas identified as being most affected
- Also involved: six local health and social-care units and 14 municipalities (seven exposed and seven unexposed).
- Sampling: Serum samples were taken from 507 people aged 20–49 years. The participants were also requested to complete a questionnaire on their dietary habits, water-supply sources and consumption of local food. Because of the contribution of other factors to PFAS body burden, the biomonitoring study also included a subgroup of 120 people living and working in agricultural areas, or working with livestock.

Separately, WHO describes a Health Surveillance Plan:

- Dates: Started in December 2016.
- Population: The Plan covers five local health units and involves almost 85 000 people between the ages of 14 and 65 years
- Objectives: To identify areas of expected/possible health impact, using data on PFAS contamination of the water supply before the installation of filters.
- Screening activities: Biennial screening of the exposed population for cancer was introduced, starting with 14 year-olds in December 2016. The reason for choosing youth to begin with was that unhealthy lifestyles are not associated with this age group; thus, if high PFAS concentrations and/or significant metabolic changes were found, they could provide an insight into the correlation between exposure to PFAS and health outcomes. People with unhealthy lifestyles are informed of the risks to their health and provided with support in modifying their behaviour. Those with PFAS serum concentrations higher than the median for the Italian population, and/or showing biochemical or blood-pressure changes, are taken over by their family doctors and placed on a second-level care path for the timely diagnosis of diseases related to PFAS exposure. The Veneto Region has a regional PFAS screening information system, which manages the entire survey process, from the mailing of invitation letters to the delivery of the results and the development of the most representative health indicators. The programme is completely free of charge for the target population. An ad hoc surveillance plan is scheduled for pregnant women and those working in the manufacture of these substances.

A series of further studies were initiated:

- ecological study of pregnancy and birth outcomes;
- occupational retrospective cohort study of employees at the chemical plant;
- retrospective ecological study of the exposed population considering mortality and morbidity data in the region over the period 2007–2014;
- retrospective ecological studies on cancer incidence over the period 1997–2013.

Costs were reported above as EUR 4.3 million, equivalent to EUR 50 per person covered by the plan. WHO reports that this covers only the first two years of the Health Surveillance Plan.

Biomonitoring has been carried out around Ronneby Airport in Sweden since 2014, following identification of PFAS contamination. The following costs have been identified[406] (see Table A3.7):

Table A3.7: Biomonitoring costs related to PFAS contamination around Ronneby Airport, 2014–2018.

Year	Activity	Cost
2014–2015	Risk assessment, risk communication, advice related to bio-monitoring study	EUR 52,000
2014–2015	PFAS analyses related to bio-monitoring study	EUR 170,000
2014	Bio-monitoring study (not more specified)	EUR 420,000
2015	Bio-monitoring study (not more specified)	EUR 460,000
2016	Bio-monitoring study (not more specified)	EUR 700,000
2017	Bio-monitoring study (not more specified)	EUR 450,000
2018	Bio-monitoring study (not more specified)	EUR 340,000
2014–2018	Average annual cost of biomonitoring study (including analyses)	EUR 510,000

Part 2: Data used in the aggregation of costs

Additional data have been used in the aggregation of costs presented in Section 4.2 of the study, as follows:

- Population (Table A3.8)
- Water consumption (Table A3.9)
- Number of wastewater treatment plant (WWTP) (Table A3.10)
- Number of plant or sources providing drinking water (Table A3.11)
- Number of airports (Table A3.12)
- Number of landfill and incineration sites (Table A3.13)

Information covers the EU28, Norway and Iceland to the extent that data are available. Data for the USA are also included for reference, given that much of the information used in this report is of US origin.

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[406] Personal communication, K. Jakobsson, Oct 2018.

Much of the analysis is based on extrapolation against estimates of the population affected. The population data provided in Table A3.8 are taken from Eurostat and the median projections under the UN's World Population Prospects. Some countries show a significant increase in population over the coming years (e.g. Denmark, France, Iceland, Luxembourg, Norway and Sweden), others show little change (e.g. Czechia, Finland, Germany, Italy, Slovakia) and some others a fall in population (e.g. Bulgaria, Greece, Lithuania). These changes will affect any quantification based on extrapolation of existing data on population.

Table A3.8: Population, 2015–2050. Source: Eurostat for EU28, UN median projections for others

	2015	2020	2030	2040	2050
Austria	8,576,261	9,005,487	9,675,572	10,087,623	10,247,691
Belgium	11,208,986	11,580,268	12,264,124	12,844,259	13,273,155
Bulgaria	7,202,198	6,954,254	6,408,361	5,933,535	5,564,146
Croatia	4,225,316	4,091,559	3,954,893	3,819,863	3,674,791
Cyprus	847,008	869,041	919,997	954,320	984,402
Czechia	10,538,275	10,652,407	10,691,890	10,552,301	10,478,190
Denmark	5,659,715	5,887,449	6,298,421	6,564,333	6,685,016
Estonia	1,313,271	1,317,940	1,306,181	1,283,732	1,256,975
Finland	5,471,753	5,561,792	5,697,608	5,722,378	5,687,527
France	66,415,161	67,818,978	70,525,154	72,915,525	74,376,832
Germany	81,197,537	83,751,689	84,613,298	84,133,642	82,686,973
Greece	10,858,018	10,560,467	9,944,658	9,419,973	8,918,545
Hungary	9,855,571	9,789,630	9,665,170	9,471,313	9,287,196
Iceland	336,728	354,222	383,538	403,548	415,151
Ireland	4,628,949	4,852,123	5,146,475	5,396,380	5,693,430
Italy	60,795,612	60,718,572	60,350,475	59,982,002	58,968,137
Latvia	1,986,096	1,911,668	1,743,960	1,598,786	1,506,055
Lithuania	2,921,262	2,749,762	2,410,874	2,128,883	1,957,377
Luxembourg	562,958	628,950	754,522	860,808	938,416
Malta	429,344	452,542	488,632	505,921	513,081
Netherlands	16,900,726	17,410,756	18,393,443	19,035,643	19,235,467
Norway	5,166,493	5,403,704	5,878,930	6,268,216	6,568,489
Poland	38,005,614	37,930,818	37,213,790	35,840,028	34,372,849
Portugal	10,374,822	10,209,628	9,880,173	9,553,608	9,116,350
Romania	19,870,647	19,259,049	18,023,954	17,069,777	16,331,359
Slovakia	5,421,349	5,458,718	5,464,199	5,373,043	5,261,609
Slovenia	2,062,874	2,075,778	2,080,145	2,066,086	2,045,090
Spain	46,449,565	46,562,044	47,110,106	48,244,792	49,257,477
Switzerland	8,238,610	8,647,547	9,477,452	10,234,794	10,977,129
Sweden	9,747,355	10,293,412	11,237,236	11,994,364	12,681,084
UK	64,875,165	67,236,507	71,563,991	75,004,352	77,568,588
EU28	508,401,408	515,591,288	523,827,302	528,357,270	528,567,808
USA	325,127,634	337,983,029	362,628,830	383,165,322	400,853,042

Data on total water consumption are shown in Table A3.9 covering not only drinking water but also industrial, agricultural and commercial uses. Overall, most supplies (80%) are taken from surface water. However, data demonstrate significant variation between countries with respect to the reliance on ground water, with Denmark and Malta obtaining more than 90% of their water from groundwater, whilst Bulgaria, Romania and Finland take more than 90% of their water from surface sources.

Table A3.9: Water consumption by country and source, million m³

Million m³	Surface	Ground	Surface + ground	Total gross abstraction	% surface	% ground
Austria						
Belgium	4,480	632	5,082	4,480	88%	12%
Bulgaria	5,071	558	5,629	5,071	90%	10%
Croatia	225	428	653	225	34%	66%
Cyprus	82	150	232	82	35%	65%
Czech Republic	1,237	366	1,603	1,237	77%	23%
Denmark	9	737	746	9	1%	99%
Estonia	1,525	199	1,724	1,525	88%	12%
Finland	6,298	264	6,562	6,298	96%	4%
France	24,400	5,608	30,008	24,400	81%	19%
Germany	27,195	5,841	33,036	27,195	82%	18%
Greece	4,297	5,611	9,908	4,297	43%	57%
Hungary	4,516	492	5,051	4,516	89%	10%
Iceland			3,011			
Ireland	561	196	757	561	74%	26%
Italy						
Latvia	92	155	248	92	37%	63%
Lithuania	254	157	411	254	62%	38%
Luxembourg	20	26	45	20	43%	57%
Malta	3	43	45	3	6%	94%
Netherlands	8,465	1,016	9,482	8,465	89%	11%
Norway						
Poland	8,486	2,608	11,094	8,486	76%	24%
Portugal						
Romania	5,868	590	6,458	5,868	91%	9%
Slovakia	248	326	574	248	43%	57%
Slovenia	714	182	895	714	80%	20%
Spain	26,613	6,304	32,916	26,613	81%	19%
Sweden	2,342	348	2,690	2,342	87%	13%
Switzerland	1,000	1,005	2,005	1,000	50%	50%
United Kingdom	5,232	2,053	7,285	5,232	72%	28%

Table A3.10 shows the number of waste water treatment plants in the EU28, Iceland and Norway. Data are taken from Eurostat, and show information for the latest year for which data are available for each country. In most cases data are taken from the period 2010–2014. Older data are highlighted in red. Data for "urban" and "other" sites have been combined. The columns indicate different levels of treatment, as follows:

- T1: Primary treatment only, removing solid material
- T2: Secondary treatment, as T1 but also digesting dissolved and suspended organic materials, sometimes with disinfection to kill pathogenic bacteria
- T3: Tertiary treatment, as T2, but with a "polishing treatment" such as the use of microfiltration or synthetic membranes to further purify the water
- T3N: T3 plant with additional nitrogen removal (included in T3 total, and will include some plant also with phosphorus removal)
- T3P: T3 plant with additional phosphorus removal (included in T3 total, and will include some plant also with nitrogen removal).

Table A3.10: Number of waste water treatment plant, category other + urban, in the EU28, Iceland and Norway

	Total	T1	T2	T3 (total)	T3N	T3P
Austria	1,842	-	791	1,051	806	889
Belgium	1,222	412	485	325	255	251
Bulgaria	90	10	54	26	26	22
Croatia	316	195	109	12	15	1
Cyprus	*191*	-	*133*	*88*	*7*	*6*
Czechia	2,636	50	1,314	1,272	546	83
Denmark	906	177	273	456	311	446
Estonia	1,044	216	539	289	98	231
Finland	202	-	-	202	50	202
France	3,275	23	647	2,605	2,516	1,719
Germany	12,590	2,307	4,824	4,028	3,540	3,112
Greece	235	-	35	200	198	130
Hungary	739	10	278	451	338	369
Iceland	*18*	*13*	*13*	-	-	-
Ireland	1,063	217	536	310	30	215
Italy	2,717	178	510	1,876	1,345	838
Latvia	1,165	207	640	48	11	-
Lithuania	717	78	578	61	56	56
Luxembourg	251	130	98	24	2	1
Malta	4	1	3	-	3	-
Netherlands	555	4	158	393	332	311
Norway	2,240	1,565	83	592	-	-
Poland	4,296	363	2,970	963	-	-
Portugal	*4,287*	-	*1,617*	*116*	-	-
Romania	826	219	518	89	47	27
Slovakia	*568*	*125*	*346*	*97*	*84*	*34*
Slovenia	352	4	314	36	32	24
Spain	2,041	35	974	1,032	722	509
Sweden	1,243	-	325	918	132	960
UK	*8,047*	*740*	*5,151*	*2,156*	-	-
Total	55,678	7,279	24,316	19,716	11,502	10,436

Note: Italics used where latest data are from before 2010. Blank cells: no data or zero

Source: Eurostat Database, Wastewater treatment plants by treatment level [env_ww_plt].

Numbers of waters supply zones are shown in Table A3.11. It seems likely that the use of filters of some kind would be applied to larger sites, whilst for smaller sites it may be more economical to provide water from alternative sources. Significant variation is seen between countries. For example, in the Netherlands very few people are served by small supplies or very small supplies, whilst these serve around 50% of the population in Lithuania.

Table A3.11: Number of water supply zones in the EU28, Iceland and Norway*

	Total number of supply zones	Large zones (>1,000 m^3/d), >5,000 persons	Small zones (10-1,000 m^3/d), 50-5,000 persons	Small zones: number of consumers	Very small zones (<10m^3/d), <50 persons	Very small zones: number of consumers
Austria	8,708	208	8,500	1,750,000	31,000 + 170,000	750,000
Belgium	1,113					
Bulgaria	42					
Croatia						
Cyprus	10					
Czech Republic	3,001	*211*	2,790	1,630,000	>500 public + 500,000 private wells	1.1 million to 3 million at weekends
Denmark			1,300		70,000	71,300
Estonia	1,220					
Finland	1,359	*159*	1,200	900,000	thousands[5]	
France	29,101		20,500	16,500,000	7,100	120,000
Germany	6,959		~500,000 people (0.7%) are not served by centralised supply[3]			
Greece	830	*30*	800	1,600,000		
Hungary	300		1,750	3,300,000	50	1,500
Iceland						
Ireland	6,900		2,275	560,000	200,000	700,000
Italy	2,000					
Latvia			497	142,095	19	2,373
Lithuania	2,044	*208*	1,836	500,000	300,000	900,000
Luxembourg	118	*20*	98	180,000	25	400
Malta	22	*2*	20	430,000	0	0
Netherlands	185	*10*	175	80,000	0	0
Norway						
Poland	26,710		10,815	11,074	8,956	
Portugal	3,356		2,068		1,000	
Romania	2,910		4,000	4,500,000	11,000	
Slovakia	2,872					
Slovenia	1,080	*284*	796	364,471		
Spain	5,552					
Sweden	4,300				800k private wells [4]	1.2 million permanent
Switzerland						
UK	2,914	1,433 [2]	266 [1]	222,488 [1]	24,000 [1]	95,000 [1]

Note: Cells in *Italics* calculated by subtraction of small from large zones where appropriate.

1) UK data for small and very small zones only available for Northern Ireland and Scotland.
2) Source: https://www.gov.uk/government/publications/water-and-treated-water/water-and-treated-water.
3) Source: https://www.umweltbundesamt.de/en/topics/water/drinking-water/small-scale-drinking-water-supplies#textpart-2
4) Source: Banzhaf *et al.* (2016) https://link.springer.com/article/10.1007/s13280-016-0848-8.
* Extracted from http://nccph.netedit.info/docs/05_small_water_systems_ver_june2005.pdf, with newer data added where available (see notes).
5) Finland estimates that thousands of very small supplies exists but also do not know the number of users.

Table A3.12 shows the number of sites that may use AFFFs in each country, totalling 694 airports and airbases, and 84,000 fire stations. Data are not complete, lacking small airports and possibly fire stations not intended primarily to serve the public and businesses generally, for example site emergency services at some industrial facilities, for example oil refineries. The omission of small airports may or may not be significant to the analysis: they may be less likely to use AFFFs (e.g. fire training may be coordinated at larger airports), but are also less likely to have effective containment in place. The aviation industry is also a significant user of PFAS in hydraulic fluid [407], though unlike AFFFs these are not deliberately released to the environment.

Table A3.12: Number of public airports, military airbases and fire stations unrelated to aviation, by country

Country	Main airports (>150k passenger/y)[1]	Other airports (between 15k and 150k passenger/y)[1]	Military (air) bases[2]	Total Airports + Airbases	Fire stations[3]
Total: EU,EFTA	318	137	239	694	84,099
Austria	6	0	5	11	5,199
Belgium	5	0	9	14	252
Bulgaria	3	1	8	12	220
Croatia	7	2	4	13	1,923
Cyprus	2	0	2	4	31
Czechia	3	2	7	12	7,561
Denmark	6	2	5	13	295
Estonia	1	1	1	3	187
Finland	9	8	7	24	988
France	44	18	38	100	6,897
Germany	25	16	25	66	33,460
Greece	20	14	13	47	275
Hungary	2	2	4	8	302
Iceland	1	0	1	2	
Ireland	5	2	1	8	220
Italy	33	2	12	47	902
Latvia	1	0	1	2	92
Lithuania	3	0		3	83
Luxembourg	1	0		1	
Malta	1	0		1	
Netherlands	5	0	12	17	1,206
Norway	1	29	12	42	597
Poland	12	0	7	19	16,805
Portugal	8	5	9	22	473
Romaia	8	4	1	13	282
Slovakia	2	2	4	8	116
Slovenia	1	0	1	2	1,359
Spain	34	4	6	44	
Sweden	19	11	5	35	1,002
Switzerland	18	1	6	25	1,319
UK	32	11	33	76	2,053

Note: 1) Eurostat Air Transport Statistics AIRP_TYP_ Number of Commercial Airports.
2) Sufficient official data has not been found, figures are based on Wikipedia for each country, and it is not clear which numbers include inactive bases.
3) International Association of Fire and Rescue Services (2017). World Fire Statistics.

The omission of industrial facilities could be significant. RPA/BRE (2004) reported that 0.76 tonnes of PFOS based substance was held in Fire Authority inventories, whilst 23.7 tonnes was held in emergency stores at industrial complexes. Training at these sites

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[407] RPA and BRE Environment (2004). Perfluorooctane Sulphonate: Risk reduction strategy and analysis of advantages and drawbacks. Report no: J454/PFOS RRS.

may or may not involve use of PFAS-containing materials, containment in training areas may or may not be effective.

The number of landfill sites in each country is shown in Table A3.13, divided into landfills for hazardous waste, non-hazardous waste and inert waste. Hazardous waste covers materials that are toxic to humans, ecotoxic, carcinogenic, teratogenic, explosive etc (a complete list is provided in Annex III of the Directive on Hazardous Waste [408], and material meeting any of definitions is classified as hazardous). Hazardous waste landfills would be appropriate to any material significantly contaminated with PFAS, including filters and soils. Inert waste covers any material that will not react, degrade, dissolve or burn, with criteria set for leachability limits and hence should not include anything containing PFAS. Non-hazardous waste includes any other materials and would contain materials such as carpets, shoes, etc. that are contaminated with PFAS, but at lower concentration than material sent for hazardous waste disposal.

Table A3.13: Number of landfill sites and incinerators in the EU28, Iceland and Norway

	Disposal - landfill (D1, D5, D12)	Disposal - landfill for HW	Disposal - landfill for non-HW	Disposal - landfill for inert waste	Disposal - incineration (D10)
Austria	189	0	153	36	1
Belgium	64	9	51	4	117
Bulgaria	187	8	176	3	
Croatia	146	0	145	1	2
Cyprus	7	1	4	2	1
Czech Republic	263	38	147	78	35
Denmark	41	5	30	6	3
Estonia	15	7	6	2	2
Finland	227	29	155	43	18
France	918	16	245	657	0
Germany	1,147	34	308	805	93
Greece	178	2	176	0	132
Hungary	111	13	92	6	13
Iceland					
Ireland	35				6
Italy	470	10	275	185	100
Latvia	13	2	11	0	4
Lithuania	14	0	11	3	2
Luxembourg	13	0	2	11	1
Malta	1	0	1	0	1
Netherlands	40	1	39	:	3
Norway	111	10	82	19	1
Poland	701	49	643	9	85
Portugal	60	2	54	4	7
Romania	129	7	122	0	20
Slovakia	118	11	92	15	11
Slovenia	37	1	26	10	4
Spain	520	35	302	183	51
Sweden	227	49	111	67	8
United Kingdom	594	26	342	226	87
Total	*6,582*	*365*	*3,801*	*2,381*	*808*

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[408] Council Directive of 12 December 1991 on hazardous waste (91 / 689 /EEC).

Part 3: Full cost estimates by country

Full cost estimates, by country, are provided in the following tables:

- the estimated costs for a basic screening programme (Table A3.14);
- the estimated costs of monitoring at contaminated sites (Table A3.15);
- estimated costs for water treatment works to reduce exposure to PFAS above possible limits (Table A3.16);
- estimated costs for soil remediation (Table A3.17);
- estimated costs for health assessment when contamination is found (Table A3.18);
- aggregated costs covering environmental screening, monitoring where contamination is found, water treatment, soil remediation and health assessment (Table A3.19).

Table A3.14: Estimated costs for a basic screening programme

	N facilities for best estimate	Best estimate, EUR million	Low, EUR million	High, EUR million
Austria	806	EUR 0.82	EUR 0.14	EUR 3.22
Belgium	148	EUR 0.15	EUR 0.04	EUR 0.59
Bulgaria	39	EUR 0.04	EUR 0.01	EUR 0.13
Croatia	141	EUR 0.14	EUR 0.03	EUR 0.54
Cyprus	25	EUR 0.03	EUR 0.01	EUR 0.07
Czechia	736	EUR 0.75	EUR 0.17	EUR 2.83
Denmark	78	EUR 0.08	EUR 0.02	EUR 0.31
Estonia	131	EUR 0.13	EUR 0.03	EUR 0.51
Finland	184	EUR 0.19	EUR 0.06	EUR 0.65
France	2024	EUR 2.06	EUR 0.37	EUR 8.04
Germany	2771	EUR 2.83	EUR 0.53	EUR 10.95
Greece	89	EUR 0.09	EUR 0.02	EUR 0.36
Hungary	119	EUR 0.12	EUR 0.05	EUR 0.39
Iceland	7	EUR 0.01	EUR 0.00	EUR 0.02
Ireland	413	EUR 0.42	EUR 0.07	EUR 1.66
Italy	300	EUR 0.31	EUR 0.05	EUR 1.22
Latvia	69	EUR 0.07	EUR 0.01	EUR 0.28
Lithuania	151	EUR 0.15	EUR 0.03	EUR 0.59
Luxembourg	21	EUR 0.02	EUR 0.00	EUR 0.08
Malta	19	EUR 0.02	EUR 0.01	EUR 0.04
Netherlands	111	EUR 0.11	EUR 0.03	EUR 0.42
Norway	179	EUR 0.18	EUR 0.04	EUR 0.68
Poland	2447	EUR 2.50	EUR 0.42	EUR 9.81
Portugal	422	EUR 0.43	EUR 0.08	EUR 1.67
Romania	209	EUR 0.21	EUR 0.04	EUR 0.84
Slovakia	191	EUR 0.19	EUR 0.04	EUR 0.75
Slovenia	165	EUR 0.17	EUR 0.04	EUR 0.62
Spain	539	EUR 0.55	EUR 0.11	EUR 2.11
Sweden	411	EUR 0.42	EUR 0.12	EUR 1.50
Switzerland	114	EUR 0.12	EUR 0.02	EUR 0.45
UK	714	EUR 0.73	EUR 0.15	EUR 2.80
Total	13,772	EUR 14.05	EUR 2.77	EUR 54.13

Best estimate assumptions

1. All airports and PFAS manufacturing sites are screened, assume 3 samples, using best estimate of cost/sample for monitoring.
2. 5% of other facilities are screened (fire stations, waste water treatment works, large and small supplies, hazardous and MSW landfills), assume 3 samples.
3. Best estimate of costs adopted.

Low estimate assumptions

1. All airports and PFAS manufacturing sites are screened, assume 3 samples, using low cost/sample monitoring.
2. 1% of other facilities are screened (fire stations, waste water treatment works, large and small supplies, hazardous and MSW landfills), assume 3 samples.
3. Low estimate of costs adopted.

High estimate assumptions

1. All airports and PFAS manufacturing sites are screened, assume 5 samples at each site, using high cost/sample for monitoring.
2. 10% of other facilities are screened (fire stations, waste water treatment works, large and small supplies, hazardous and MSW landfills), assume 3 samples.
3. High estimate of costs adopted.

Table A3.15: Estimated costs of monitoring at contaminated sites

	N facilities for best estimate	Best estimate, EUR millions, airfields and PFASmanufacturing only, EUR million	Best estimate, all source categories included, EUR million	Low, EUR millions	High, EUR millions
Austria	81	EUR 0.11	EUR 4.05	EUR 0.43	EUR 81.17
Belgium	16	EUR 0.16	EUR 0.81	EUR 0.11	EUR 16.22
Bulgaria	4	EUR 0.12	EUR 0.21	EUR 0.04	EUR 4.51
Croatia	15	EUR 0.12	EUR 0.73	EUR 0.09	EUR 14.73
Cyprus	4	EUR 0.13	EUR 0.19	EUR 0.04	EUR 3.14
Czechia	79	EUR 0.67	EUR 3.97	EUR 0.50	EUR 77.14
Denmark	8	EUR 0.03	EUR 0.40	EUR 0.05	EUR 7.98
Estonia	14	EUR 0.08	EUR 0.69	EUR 0.08	EUR 13.53
Finland	22	EUR 0.47	EUR 1.11	EUR 0.19	EUR 20.81
France	206	EUR 0.47	EUR 10.29	EUR 1.11	EUR 204.72
Germany	286	EUR 1.03	EUR 14.28	EUR 1.59	EUR 282.67
Greece	9	EUR 0.13	EUR 0.47	EUR 0.07	EUR 10.20
Hungary	16	EUR 0.47	EUR 0.81	EUR 0.15	EUR 14.35
Iceland	1	EUR 0.04	EUR 0.05	EUR 0.01	EUR 0.86
Ireland	41	EUR 0.02	EUR 2.07	EUR 0.21	EUR 41.40
Italy	29	EUR 0.05	EUR 1.45	EUR 0.16	EUR 30.77
Latvia	7	EUR 0.01	EUR 0.35	EUR 0.04	EUR 6.99
Lithuania	16	EUR 0.08	EUR 0.79	EUR 0.09	EUR 15.49
Luxembourg	2	EUR 0.01	EUR 0.11	EUR 0.01	EUR 2.14
Malta	4	EUR 0.17	EUR 0.18	EUR 0.04	EUR 2.79
Netherlands	12	EUR 0.12	EUR 0.61	EUR 0.08	EUR 11.75
Norway	19	EUR 0.20	EUR 0.97	EUR 0.13	EUR 18.87
Poland	243	EUR 0.22	EUR 12.17	EUR 1.27	EUR 246.24
Portugal	43	EUR 0.13	EUR 2.16	EUR 0.24	EUR 42.85
Romania	20	EUR 0.02	EUR 1.02	EUR 0.11	EUR 21.14
Slovakia	19	EUR 0.08	EUR 0.97	EUR 0.11	EUR 19.55
Slovenia	19	EUR 0.24	EUR 0.94	EUR 0.13	EUR 17.71
Spain	56	EUR 0.35	EUR 2.79	EUR 0.34	EUR 55.89
Sweden	48	EUR 0.76	EUR 2.40	EUR 0.36	EUR 44.97
Switzerland	11	EUR 0.02	EUR 0.57	EUR 0.06	EUR 11.52
UK	74	EUR 0.45	EUR 3.70	EUR 0.45	EUR 74.10
Total	*1,426*	*EUR 6.96*	*EUR 71.28*	*EUR 8.30*	*EUR 1,416*

Best estimate assumptions

1. Assumed 20% of airports and PFAS manufacturing sites require monitoring programme, using best estimate cost/case for monitoring.
2. 0.5% of other facilities require monitoring.
3. Best estimate of costs adopted.

Low estimate assumptions

1. Assumed 10% of airports and PFAS manufacturing sites require monitoring programme, using low estimate cost/case for monitoring.
2. 0.1% of other facilities require monitoring.
3. Low estimate of costs adopted.

High estimate assumptions

1. Assumed 30% of airports and PFAS manufacturing sites require monitoring programme, using high estimate cost/case for monitoring.
2. 1% of other facilities require monitoring.
3. High estimate of costs adopted.

Table A3.16: Estimated costs for water treatment works to reduce exposure to PFAS above possible limits

	Population affected, best estimate	Best estimate, EUR millions	Low, EUR millions	High, EUR millions
Austria	257,288	EUR 146	EUR 11	EUR 415
Belgium	336,270	EUR 191	EUR 15	EUR 542
Bulgaria	216,066	EUR 123	EUR 9	EUR 348
Croatia	126,759	EUR 72	EUR 6	EUR 204
Cyprus	25,410	EUR 14	EUR 1	EUR 41
Czechia	316,148	EUR 180	EUR 14	EUR 510
Denmark	169,791	EUR 97	EUR 7	EUR 274
Estonia	39,398	EUR 22	EUR 2	EUR 64
Finland	164,153	EUR 93	EUR 7	EUR 265
France	1,992,455	EUR 1,133	EUR 87	EUR 3,213
Germany	2,435,926	EUR 1,385	EUR 106	EUR 3,928
Greece	325,741	EUR 185	EUR 14	EUR 525
Hungary	295,667	EUR 168	EUR 13	EUR 477
Iceland	10,102	EUR 6	EUR 0	EUR 16
Ireland	138,868	EUR 79	EUR 6	EUR 224
Italy	1,823,868	EUR 1,037	EUR 80	EUR 2,941
Latvia	59,583	EUR 34	EUR 3	EUR 96
Lithuania	87,638	EUR 50	EUR 4	EUR 141
Luxembourg	16,889	EUR 10	EUR 1	EUR 27
Malta	12,880	EUR 7	EUR 1	EUR 21
Netherlands	507,022	EUR 288	EUR 22	EUR 818
Norway	154,995	EUR 88	EUR 7	EUR 250
Poland	1,140,168	EUR 648	EUR 50	EUR 1,838
Portugal	311,245	EUR 177	EUR 14	EUR 502
Romania	596,119	EUR 339	EUR 26	EUR 961
Slovakia	162,640	EUR 92	EUR 7	EUR 262
Slovenia	61,886	EUR 35	EUR 3	EUR 100
Spain	1,393,487	EUR 792	EUR 61	EUR 2,247
Sweden	292,421	EUR 166	EUR 13	EUR 472
Switzerland	247,158	EUR 141	EUR 11	EUR 399
UK	1,946,255	EUR 1,107	EUR 85	EUR 3,138
Total	*15,664,297*	*EUR 8,906*	*EUR 684*	*EUR 25,258*

Best estimate assumptions

1. Assumed 3% of the population are exposed to excess levels of PFAS via drinking water.
2. Assume 20 year maintenance programme for treatment works, based on best estimate.
3. Assume best estimate cost per case for remediation.
4. Assume 4% discount rate on future maintenance costs.

Low estimate assumptions

1. Assumed 1% of the population are exposed to excess levels of PFAS via drinking water.
2. Assume 20 year maintenance programme for treatment works, based on best estimate.
3. Assume low estimate cost per case for remediation.
4. Assume 4% discount rate on future maintenance costs.

High estimate assumptions

1. Assumed 5% of the population are exposed to excess levels of PFAS via drinking water.
2. Assume 20 year maintenance programme for treatment works, based on best estimate.
3. Assume high estimate cost per case for remediation.
4. Assume 4% discount rate on future maintenance costs.

Table A3.17: Estimated costs for soil remediation

	N facilities for best estimate	Best estimate, EUR millions, airfields and PFAS manufacturing only, EUR milions	Best estimate, all source categories included, EUR milions	Low, EUR millions	High, EUR millions
Austria	81	11.0	EUR 405	EUR 5.1	EUR 8,117
Belgium	16	16.0	EUR 81	EUR 1.3	EUR 1,622
Bulgaria	4	12.0	EUR 21	EUR 0.5	EUR 451
Croatia	15	12.0	EUR 73	EUR 1.1	EUR 1,473
Cyprus	4	13.0	EUR 19	EUR 0.5	EUR 314
Czechia	79	67.0	EUR 397	EUR 6.0	EUR 7,714
Denmark	8	3.0	EUR 40	EUR 0.5	EUR 798
Estonia	14	8.0	EUR 69	EUR 1.0	EUR 1,353
Finland	22	47.0	EUR 111	EUR 2.2	EUR 2,081
France	206	47.0	EUR 1,029	EUR 13.3	EUR 20,472
Germany	286	103.0	EUR 1,428	EUR 19.1	EUR 28,267
Greece	9	13.0	EUR 47	EUR 0.9	EUR 1,020
Hungary	16	47.0	EUR 81	EUR 1.8	EUR 1,435
Iceland	1	4.0	EUR 5	EUR 0.1	EUR 86
Ireland	41	2.0	EUR 207	EUR 2.5	EUR 4,140
Italy	29	5.0	EUR 145	EUR 2.0	EUR 3,077
Latvia	7	1.0	EUR 35	EUR 0.4	EUR 699
Lithuania	16	8.0	EUR 79	EUR 1.1	EUR 1,549
Luxembourg	2	1.0	EUR 11	EUR 0.1	EUR 214
Malta	4	17.0	EUR 18	EUR 0.5	EUR 279
Netherlands	12	12.0	EUR 61	EUR 1.0	EUR 1,175
Norway	19	20.0	EUR 97	EUR 1.6	EUR 1,887
Poland	243	22.0	EUR 1,217	EUR 15.2	EUR 24,624
Portugal	43	13.0	EUR 216	EUR 2.8	EUR 4,285
Romania	20	2.0	EUR 102	EUR 1.3	EUR 2,114
Slovakia	19	8.0	EUR 97	EUR 1.3	EUR 1,955
Slovenia	19	24.0	EUR 94	EUR 1.6	EUR 1,771
Spain	56	35.0	EUR 279	EUR 4.1	EUR 5,589
Sweden	48	76.0	EUR 240	EUR 4.3	EUR 4,497
Switzerland	11	2.0	EUR 57	EUR 0.7	EUR 1,152
UK	74	45.0	EUR 370	EUR 5.4	EUR 7,410
Total	*1,426*	*696*	*EUR7,128*	*EUR 100*	*EUR 141,613*

Best estimate assumptions

1. Assumed 20% of airports and PFAS manufacturing sites require remediation.
2. 0.5% of other facilities require remediation.
3. Best estimate of costs adopted.

Low estimate assumptions

1. Assumed 10% of airports and PFAS manufacturing sites require remediation.
2. 0.1% of other facilities require remediation.
3. Low estimate of costs adopted.

High estimate assumptions

4. Assumed 30% of airports and PFAS manufacturing sites require remediation.
5. 1% of other facilities require remediation.
6. High estimate of costs adopted.

Table A3.18: Estimated costs for health assessment when contamination is found

	Population affected, best estimate	Best estimate, EUR millions	Low, EUR millions	High, EUR millions
Austria	257,288	EUR 13	EUR 0.43	EUR 41
Belgium	336,270	EUR 17	EUR 0.56	EUR 53
Bulgaria	216,066	EUR 11	EUR 0.36	EUR 34
Croatia	126,759	EUR 6	EUR 0.21	EUR 20
Cyprus	25,410	EUR 1	EUR 0.04	EUR 4
Czechia	316,148	EUR 16	EUR 0.53	EUR 50
Denmark	169,791	EUR 8	EUR 0.28	EUR 27
Estonia	39,398	EUR 2	EUR 0.07	EUR 6
Finland	164,153	EUR 8	EUR 0.27	EUR 26
France	1,992,455	EUR 100	EUR 3.32	EUR 315
Germany	2,435,926	EUR 122	EUR 4.06	EUR 386
Greece	325,741	EUR 16	EUR 0.54	EUR 52
Hungary	295,667	EUR 15	EUR 0.49	EUR 47
Iceland	10,102	EUR 1	EUR 0.02	EUR 2
Ireland	138,868	EUR 7	EUR 0.23	EUR 22
Italy	1,823,868	EUR 91	EUR 3.04	EUR 289
Latvia	59,583	EUR 3	EUR 0.10	EUR 9
Lithuania	87,638	EUR 4	EUR 0.15	EUR 14
Luxembourg	16,889	EUR 1	EUR 0.03	EUR 3
Malta	12,880	EUR 1	EUR 0.02	EUR 2
Netherlands	507,022	EUR 25	EUR 0.85	EUR 80
Norway	154,995	EUR 8	EUR 0.26	EUR 25
Poland	1,140,168	EUR 57	EUR 1.90	EUR 181
Portugal	311,245	EUR 16	EUR 0.52	EUR 49
Romania	596,119	EUR 30	EUR 0.99	EUR 94
Slovakia	162,640	EUR 8	EUR 0.27	EUR 26
Slovenia	61,886	EUR 3	EUR 0.10	EUR 10
Spain	1,393,487	EUR 70	EUR 2.32	EUR 221
Sweden	292,421	EUR 15	EUR 0.49	EUR 46
Switzerland	247,158	EUR 12	EUR 0.41	EUR 39
UK	1,946,255	EUR 97	EUR 3.24	EUR 308
Total	*15,664,297*	*EUR 783*	*EUR 26*	*EUR 2,480*

Table A3.19: Aggregated costs covering environmental screening, monitoring where contamination is found, water treatment, soil remediation and health assessment.

	Best estimate, EUR millions	Low, EUR millions	High, EUR millions
Austria	EUR 569	EUR 17	EUR 8,656
Belgium	EUR 290	EUR 16	EUR 2,234
Bulgaria	EUR 155	EUR 10	EUR 838
Croatia	EUR 152	EUR 7	EUR 1,712
Cyprus	EUR 35	EUR 2	EUR 362
Czechia	EUR 597	EUR 21	
Denmark	EUR 145	EUR 8	EUR 1,106
Estonia	EUR 94	EUR 3	EUR 1,437
Finland	EUR 214	EUR 10	EUR 2,393
France	EUR 2,274	EUR 105	EUR 24,213
Germany	EUR 2,952	EUR 132	EUR 32,874
Greece	EUR 249	EUR 16	EUR 1,607
Hungary	EUR 264	EUR 15	EUR 1,973
Iceland	EUR 12	EUR 1	EUR 105
Ireland	EUR 295	EUR 9	EUR 4,429
Italy	EUR 1,275	EUR 85	EUR 6,339
Latvia	EUR 72	EUR 3	EUR 811
Lithuania	EUR 134	EUR 5	EUR 1,720
Luxembourg	EUR 21	EUR 1	EUR 246
Malta	EUR 26	EUR 1	EUR 305
Netherlands	EUR 375	EUR 24	EUR 2,085
Norway	EUR 194	EUR 9	EUR 2,181
Poland	EUR 1,937	EUR 69	EUR 26,899
Portugal	EUR 411	EUR 17	EUR 4,880
Romania	EUR 472	EUR 28	EUR 3,191
Slovakia	EUR 199	EUR 9	EUR 2,263
Slovenia	EUR 133	EUR 5	EUR 1,899
Spain	EUR 1,144	EUR 68	EUR 8,115
Sweden	EUR 423	EUR 18	EUR 5,061
Switzerland	EUR 210	EUR 12	EUR 1,601
UK	EUR 1,579	EUR 94	EUR 10,933
Total	*EUR 16,902*	*EUR 821*	*EUR 170,821*

Best estimate assumptions

1. Assumed 3% of the population are exposed to excess levels of PFAS via drinking water.
2. Assume best estimate cost per case for remediation.

Low estimate assumptions

1. Assumed 1% of the population are exposed to excess levels of PFAS via drinking water.
2. Assume low estimate cost per case for remediation.

High estimate assumptions

1. Assumed 5% of the population are exposed to excess levels of PFAS via drinking water.
2. Assume high estimate cost per case for remediation.

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THE COST OF INACTION

PFAS (per and polyfluoroalkylsubstances) are known to be extremely difficult to degrade in the environment and to be bioaccumulative and toxic. Exposure to PFAS is suspected to increase the risk of adverse health effects, such as impacts on the thyroid gland, the liver, fat metabolism and the immune system. This study estimates the socioeconomic costs that may result from impacts on human health and the environment from the use of PFAS. Better awareness of the costs and problems associated with PFAS exposure will assist decision-makers and the general public to make more efficient and timely risk management decisions. Findings indicate that the costs are substantial, with annual health-related costs estimated to 2.8 – 4.6 billion EUR for the Nordic countries and 52 – 84 billion EUR for all EEA countries. Overall non-health costs are estimated at 46 million – 11 billion EUR for the Nordic countries.

Upon request the excel spreadsheets used for the monetarisation and valuation in this report can also be provided along with a guidance on how to use the estimation of costs for value transfer. Please contact any of the consultants or members of the steering group from the Swedish Chemicals Agency or the Danish Environmental Protection Agency if you are interested in receiving these excel spreadsheets.

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