



PFAS in the marine environment

Measures for minimising and managing PFAS
contamination in municipal operations

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KIMO Sweden is part of KIMO International

The International Municipal Environment Organization, KIMO, was founded in Denmark in 1990. KIMO's purpose is to protect the marine environment and to reduce the environmental problems caused by pollution, climate change and littering in the sea and on our beaches. KIMO works to influence legislators and decision-makers to improve the conditions for the marine environment in the North Sea and the Baltic Sea. With over 80 member municipalities in eight countries, we represent more than five million citizens in Europe.

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Preface

KIMO Sweden would like to thank Milou Grylls, who during her internship at KIMO Sweden produced this report on PFAS in the marine environment.

PFAS are a large group of man-made substances that are stable, difficult to degrade and grease- and water-repellent, which has contributed to the substances being used in everything from electronics to clothing and firefighting foam. The substances spread easily in the environment and have ecological and economic consequences, as well as posing a threat to human health. The spread and use of PFAS is a complex problem and a highly topical issue that affects many societal actors. Cooperation is needed to prevent and manage existing pollution. Municipalities have both a responsibility and opportunities to act to minimize and remedy this large-scale environmental problem. The report has been produced by KIMO Sweden and has a special focus on PFAS in the marine environment, as well as on the management of the problem in municipal operations. The report is important reading and strengthens the knowledge for us in the municipalities to continue our work for healthy and vibrant marine environments.

Karin Pleijel

President KIMO Sweden

Summary

Per- and polyfluorinated alkyl substances (hereinafter PFAS) are a group of man-made substances that have been widely used in various industries since the 1950s. They are stable, difficult to degrade and grease- and water-repellent, which has contributed to their use in everything from electronics to clothing and firefighting foam. Their properties make them mobile, which has contributed to large-scale spread in the environment. The spread has ecological and economic consequences and poses a threat to humans and animals due to the negative health effects of the substances. Since the substances have many uses, there are a large number of sources of PFAS in the environment and in Sweden the main source has been the use of firefighting foam. Runoff from treatment plants and landfills has been identified as significant pathways. The deep sea has been described as the only PFAS sink, but new research suggests that sea spray aerosols can return PFAS to the terrestrial environment and that this enables a continuous cycle of PFAS. The issue of PFAS is complex and highly topical, as it affects many societal actors. Cooperation is needed to prevent and manage existing pollution. Sweden's municipalities have an important responsibility as well as opportunities to act to minimize and remedy it.

The report has been produced by KIMO Sweden and has a special focus on PFAS in the marine environment, as well as on the management of the problem in municipal operations. The report includes general knowledge about PFAS and information on how municipalities can work to minimize their use and spread. Relevant legislation is described, as well as good examples from national and international municipalities.



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I Introduction

I.1 What is KIMO?

KIMO is the International Environmental Organization of Local Authorities, which works to protect, preserve and improve the marine environment. The organisation provides municipalities with a good platform for influencing decision-makers at regional, national and international levels. KIMO was founded in 1990 and consists of municipalities in countries around the North Sea and the Baltic Sea. Over the years, the main issues for KIMO Sweden have been marine litter, oil pollution, dumped chemical weapons, emissions of greenhouse gases and pollution, as well as sustainable shipping. The Environmental Administration of the City of Gothenburg is the national coordinator for KIMO Sweden.

I.2 Purpose

The purpose of this report is to provide municipalities with knowledge about and support in their work with PFAS and the problems that these substances create for the environment and society. The report provides an overview of what PFAS are, the main sources and routes of their spread, the consequences of their large-scale spread and relevant legislation. The municipalities' broad area of responsibility provides opportunities to take relevant measures and contribute to a better environment.

I.2.1 Boundaries

The report focuses on PFAS in the marine environment. Previously, the focus of PFAS issues in Sweden has mainly been drinking water and the activities of the Swedish Armed Forces, which will not be covered in the report. The management of PFAS needs to take place at many levels, but this report mainly aims to cover the aspects that are of greatest importance for the municipalities' responsibilities and opportunities.

2 Background

PFAS is an area of knowledge under constant development, with many critical questions left to answer. Both the number of PFAS substances and their areas of use have increased and the US Environmental Protection Agency, USEPA, has compiled a list of over 14,000 different PFAS substances.¹ The list is based on a broader definition of PFAS compared to the OECD's definition, which is the most widely accepted definition. According to the OECD, PFAS are fluorinated substances containing at least one fully fluorinated methyl group or methylene group (without any hydrogen/chlorine/bromo/iodine attaching to it).^{2(p.8)} This definition is used by the Swedish Chemicals Agency.³ Of the more than 14,000 identified substances, more than 4,700 have an identification number, which indicates that these substances are present or have appeared on the global market.² For a fraction of the substances, there are studies on how the substances affect the environment and human health.⁴

Improving and streamlining analysis methods of PFAS, understanding the consequences of the substances for humans and the environment, and how the substances can be regulated are some of the questions that need to be answered in order for the environment and people to be protected against the negative effects of PFAS substances.⁵

2.1 What are PFAS?

PFAS are a large group of man-made substances with great variation in molecular structure. This means that the substances have different chemical, biological and physical properties.² Characteristic of the substances is a carbon chain of varying lengths, where fluorine fully (perfluorinated) or partially (polyfluorinated) replaces the hydrogen atoms that are normally bound to the carbon chain,³ see Figure 1. Fluoride gives the molecule properties such as increased stability, fat solubility and makes it easier for humans and animals to absorb the substances. This makes them sought after by many industries, but at the same time problematic from an environmental and health perspective.⁶

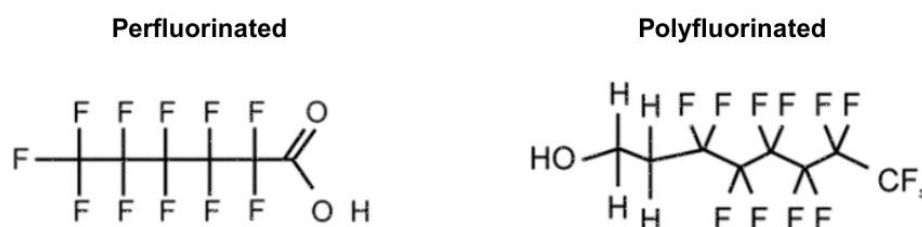


Figure 1. Description of the structure of per- and polyfluorinated molecules (from KEMI.³ Use with permission).

In short, PFAS can be divided into two classes, polymers and non-polymers. Chemical compounds that consist of smaller repeated units that together form long chains are called polymers. The non-polymeric PFAS variants are the per- or polyfluorinated carbon chains that generally have a functional group attached to them, a small part of the molecule that can strongly influence the properties of the molecule.³ Both classes can be divided into subgroups (Figure 2).

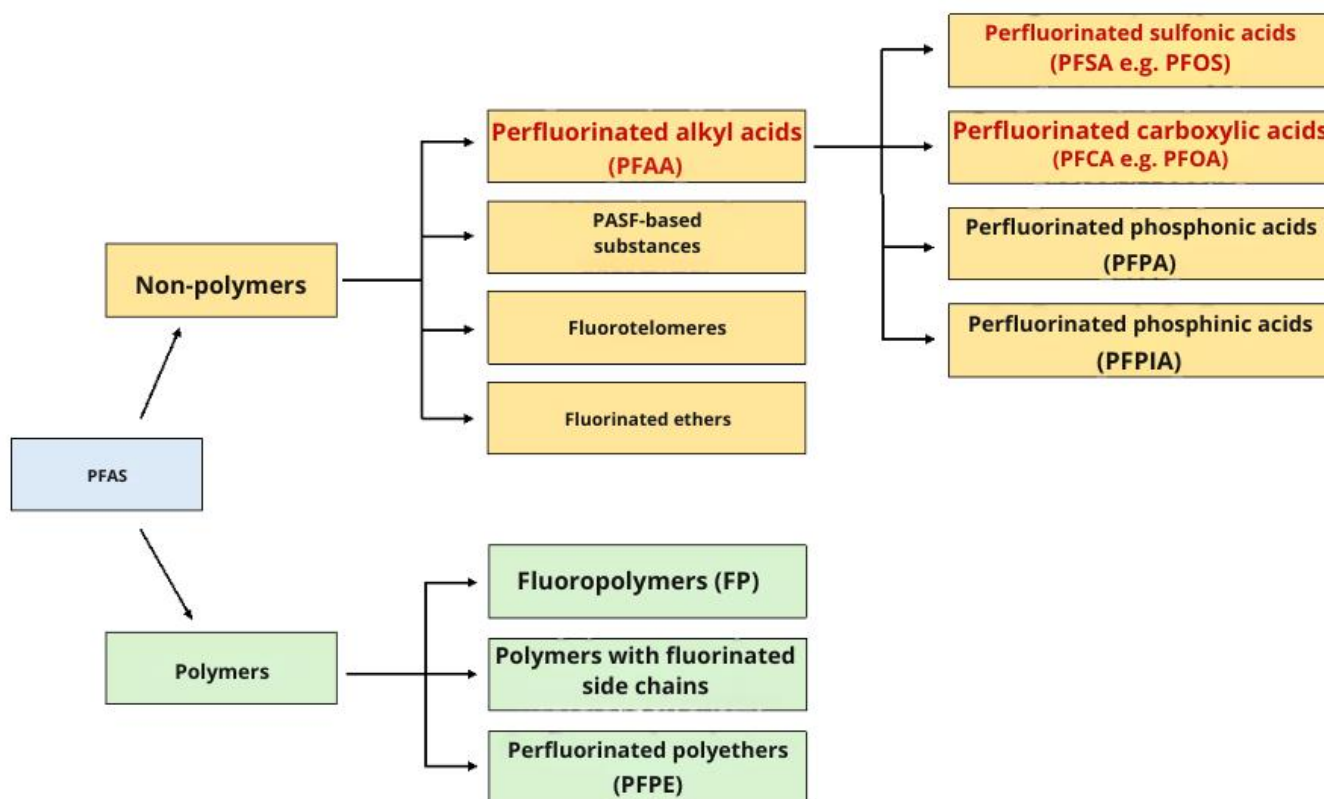


Figure 2. General classification of PFAS. A simplified version that does not include all sub-groups, but only those relevant to the report (adapted from OECD⁷).

PFAAs are a group of PFAS substances with a generally simpler molecular structure, which under normal conditions are basically indestructible. PFAAs are divided into four additional subgroups, of which PFSA and PFCA have been the substances that have been mainly sampled in the environment. For some PFSAs and PFCAs, there are existing limit values and guideline values that are used by authorities, as these have been studied for a couple of decades.⁴

2.2 Properties of the substances

The bond between carbon and fluorine atoms is the strongest known, which means that these chemical compounds are extremely difficult to break down. PFAS are also generally more water-soluble compared to other organic pollutants. Stability and water solubility give the substance the opportunity for extensive dispersion in aquatic environments.⁶

Generally, PFAS molecules consist of a water-repellent fluorinated carbon chain and a water-soluble part,³ (cf. Figure 3). This means that PFAS molecules like to settle in the interface layer between two surfaces, for example between a liquid and a solid surface, which means that they are very surfactant. The surface activity contributes to the ability to repel water and grease and to quickly form a thin film over a large area. The film-forming property has been used extensively in everything from cosmetics to ski wax and extinguishing foam. It has been particularly useful for liquid fires where the extinguishing foam quickly forms a film between the burning liquid and the air.⁶

The water-repellent and water-soluble parts of a PFAS molecule can in some cases be linked by a "coupling group", and these three parts can be varied in different ways to form new PFAS variants.³ Naturally occurring organic fluorine compounds exist, but they are few.⁸ Characteristically, they contain only one fluorine atom per molecule,⁹ unlike molecules with several fluorine atoms produced industrially.⁶

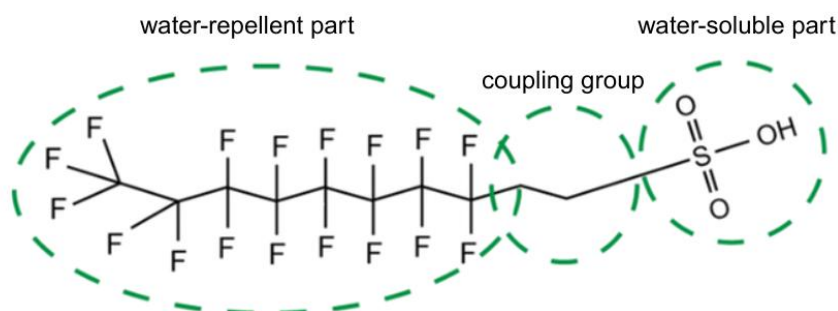


Figure 3. Example of the structure of a PFAS molecule (from KEMI.³ Use with permission).

2.2.1 Long- and short-chain PFAS

The length of the fluorinated carbon chain divides PFAS into short- and long-chain substances. It is a way of categorizing the substances because the length of the carbon chain affects the chemical properties.⁶ Short-chain PFAS substances were long considered less problematic than long-chain PFAS substances, but since the length of the carbon chain is not the only factor that affects the properties of the molecule, this is a simplistic view.³

2.3 Precursors – Partial degradation of PFAS

Substances that are partially broken down into another substance by a chemical process and reach a long-lived phase are called precursors. In the environment, many PFAS substances can be converted to PFAAs, making them precursors of PFAAs. These are important to take into account when investigating contaminated sites, as in some cases, precursors make up the majority of the PFAS found. Special chemical analyses are required to investigate the presence of precursors.⁶

3 Sources of PFAS in the environment

3.1 Known sources

In Sweden, firefighting foam has been the main direct source of PFAS to the environment¹⁰, but various industries that use PFAS in various manufacturing processes are also direct sources. Secondary sources include, for example, when waste or products containing PFAS are handled by businesses such as landfills, treatment plants and incineration plants.⁶ Treatment plants and leachate from landfills have been identified as significant secondary sources^{10, 11} and sludge from wastewater treatment plants used on agricultural land may also contain PFAS.¹² Atmospheric deposition and the use of consumer products containing PFAS are diffuse sources.⁶ Over 2000 different potential local PFAS sources have been identified in Sweden¹⁰ and in 2020 the Geological Survey of Sweden mapped sites where extinguishing foam has been handled, where over 11,000 potential point sources were included.¹³ Land and water adjacent to airports, fire drill areas, landfills and industries that use PFAS often have elevated PFAS levels. The county administrative boards have identified and mapped many of these PFAS-contaminated areas, but this knowledge can vary between the county administrative boards.¹⁴ The addition of low levels of PFAS can sometimes be seen as a trade secret, which means that the substances are only vaguely mentioned or not declared at all in safety data sheets.⁶

3.1.1 PFAS in the ocean

The deep sea has been identified as the only PFAS sink in the environment.¹⁵ In the Atlantic, the highest PFAS concentrations have been measured in the upper sea layer and the concentrations generally decrease with increasing distance from the coast and with increasing depth.¹⁶ When air is drawn into the seawater as waves break, clouds of air bubbles are formed and then rise to the surface of the sea.¹⁷ The surfactant properties of PFAS molecules cause them to accumulate at the interface of the air bubbles, and rising bubbles can thus transport PFAS to the sea surface. When the bubbles reach the sea surface, they burst and release small droplets, sea spray aerosols, with PFAS into the atmosphere.¹⁸ In the atmosphere, the sea spray aerosols transport PFAS back to land where they are returned to the terrestrial environment by rain. This is likely to prevent global PFAS levels from falling as it creates a constant and long-lived cycle of PFAS between marine and terrestrial environments.¹⁹ Aerosols have been shown in the laboratory to have around four to five orders of magnitude (10,000–100,000 times) higher PFAS concentrations compared to seawater, and field studies have shown that sea spray aerosols are a significant source of atmospheric PFAS in coastal areas.¹⁹⁻²¹

Studies in Denmark and the Netherlands have shown high levels of PFAS in sea foam along beaches^{22, 23} and in Denmark, coastal nature, pastures and groundwater have also been contaminated by PFAS, probably due to PFAS-rich sea foam and sea spray aerosols. In Denmark, the study showed that the concentration of PFAS in the terrestrial environment decreases with distance from the sea, but coastal areas can potentially have high levels of PFAS.^{22, 24} This becomes an important question if grazing animals, crops or water sources are located near the sea. A simplified picture of PFAS in the environment can be seen in Figure 4.

PFAS can also be included in antifouling paints that contain silicone, which can be a source of PFAS in the marine environment.²⁵ At the same time, it has been shown that fluorine-free silicone paint works just as well.²⁶ Wastewater treatment plants are likely to be a major source of PFAS in the marine environment because there are no suitable treatment technologies.^{10, 27} Problems arise when heavy rainfall occurs because the treatment plants find it difficult to handle the volumes, whereupon untreated wastewater can then be discharged into watercourses and coastal waters. In the UK, a research study²⁷ showed elevated PFAS levels in water and bladderwrack in a protected marine area after untreated wastewater was discharged. This is probably one of the few occasions when PFAS has been detected in a macroalgae.²⁸ Another example where PFAS have been found in macroalgae is from a study in 2023, which highlights their potential for environmental monitoring.²⁹

3.2 Uses

PFAS are often used when stable and inert substances are needed, as well as on occasions when there is a large temperature variation.³⁰ PFAS can also replace less effective substances, either because PFAS can be used in lower concentrations or because other substances do not achieve the desired effect.³¹ For many PFAS substances, there is a lack of information on production and use. In Sweden, no PFAS production has taken place, but the substances have been and are still widely used by various industries.⁶ In 2015, the Swedish Chemicals Agency mapped the uses and occurrences of PFAS for 3 000 individual substances, approximately half of which had an identified use.³² The most common uses with the most identified substances per area were compiled and can be seen in descending order in Table I.³²

Table I. Areas of use for PFAS.

Use	Example
1 Synthetic chemical	Emulsifiers, process agent
2 Electronic Product	Printed circuit boards, mobile phones, transducers
3 Printing product	Ink
4 Cosmetic Product	Foundation, sunscreen, skin cream
5 Textile/leather impregnation	Outerwear, sails, umbrellas
6 Pharmaceuticals/plant health/biocide	Plant protection (active substance and inert agent)
7 Paint/glue raw material	Paint (mainly water-based), ski wax
8 Paper Spraying	Popcorn bags, pizza boxes, masking paper
9 Fire-extinguishing agents, foam-based	Class B foam for liquid fires

3.3 Human exposure

Worldwide, many PFAS substances, mainly PFAAs, have been detected both in the environment and in humans.^{33, 34} Water, food, air, indoor dust and consumer products containing PFAS are the largest sources of exposure for humans.^{35, 36} Among foods, fish and shellfish often contain the highest concentrations, but the substances are also found in, for example, eggs, meat and milk. The substances can also be absorbed by fruit and vegetables if the soil and water are contaminated.³⁷ PFAS are widely used in plant protection products, and between 2011 and 2021, pesticide residues with PFAS in fruit and vegetables grown in the EU have almost tripled.³⁸ Despite the phasing out of PFAS substances PFOS and PFOA in the United States, humans continue to be exposed. A US study found that more than 90% of pregnant women are still exposed to PFOS and PFOA.³⁹



Figure 4. A simplified figure of the PFAS cycle with a focus on the marine environment. Sources are represented by dark red circles, transport routes with white circles, and potentially contaminated areas with orange circles.

3.4 History

The development of PFAS substances began in the 1930s. In 1938, PTFE was produced, which is marketed under the name Teflon, among other things. The development of PFAS continued during the 1940s and in the 1950s production and use became large-scale.⁴⁰ Firefighting foams with PFAS were developed in the 1960s and have been widely used worldwide since then.⁶

In 2000, a voluntary phase-out of certain long-chain PFAS substances was announced by the company 3M. The company was then the main global producer of several PFAS substances and in the United States the company was the only producer of PFOS.⁴ Subsequently, production of PFOA and other long-chain PFAS substances slowed down in the United States and, in 2015, the main producers had ceased their production.⁴¹ As a result, a global reduction in direct emissions of PFOA from the production stage was expected, but this was probably replaced by an increase in production in China, Russia and India.⁴² PFAS production in China began in the late 1980s⁴³ and the phase-out of long-chain PFAS in the United States coincided with increased PFOS production in China.⁴² Germany, Italy and China were still producing PFOS in 2016, but China was the only known producer one year later. China has been awarded grants to phase out PFOS because the country has ratified the Stockholm Convention.⁴³ In Brazil, large-scale production of a PFOS precursor used in pesticides is still taking place, which is permitted by the Stockholm Convention.⁴⁴ The United States, Europe and Japan have today stopped producing certain PFAS substances, but globally production continues.⁴

4 Consequences

PFAS can spread over long distances via ocean currents, groundwater flows and air currents.⁶ The global spread of PFAS in the environment was first reported in 2001 and several studies followed.⁴⁵ PFAS have been found in terrestrial, limnic and marine environments, as well as at all levels of the food chain. The highest concentrations are found in top predators.⁶

The negative health effects linked to PFOS and PFOA have contributed to the phasing out of long-chain PFAS. However, they were replaced by short-chain or lesser-known PFAS substances with a similar structure.^{46, 47} They were assumed to be less toxic and bioaccumulative and were marketed as safe alternatives.⁴⁸ However, short-chain PFAS have been shown to be able to spread even more widely in the environment and are at least as environmentally resilient.⁴⁹⁻⁵¹ In both surface and groundwater, some of these substitutes have been extensively discovered.^{51, 52} Studies have shown bioaccumulation of certain short-chain PFAS in both humans and animals.^{53, 54}

4.1 Impacts on marine ecosystems

PFAS are found everywhere in the marine environment. From the body of water, marine sediments and sea ice to concentrated levels of PFAS in sea foam and sea spray aerosols.^{18-23; 57-59} In the marine food chain, PFAS are found at all levels, from plankton to porpoises and sharks.⁶⁰⁻⁶² Predators at the top of the food chain can have up to four orders of magnitude (10,000 times) higher concentration compared to prey.⁶³ Adverse effects on the immune system are the primarily reported consequence for marine wildlife.^{64, 65} In bottlenose dolphins, exposure has been shown to affect blood, kidney and liver functions⁶⁶ and PFAS have also been found in the brains of polar bears.⁶⁷ Research studies on fish indicate that some of these short-chain substitutes can accumulate in greater quantities compared to long-chain PFAS substances.^{55, 56}

4.2 Consequences for people and society

The most well-studied PFAS group from an environmental and health perspective is PFAA. The first report on the presence of PFAS in human blood was published in 1968, but it was not known what specific substances were involved.⁶⁸ Analytical techniques in the 1970s were limited and it was not until the late 1990s that individual PFAS substances could be analysed.

In general, PFAS are easily absorbed by humans and unlike other bio-accumulative contaminants that tend to be stored in adipose tissue, PFAS have a propensity to bind to protein. The bloodstream spreads PFAS around the body to organs and tissues.^{67, 70-73} PFAS can cause damage to tissues because they can bind to several of the body's different receptors and proteins.⁷¹ A variety of adverse health effects from PFAS exposure in both animals and humans have been demonstrated. High levels of PFAS in people with heavy exposure have been associated with a variety of conditions, including liver damage, kidney and testicular

cancer, high cholesterol, and changes in the immune system.⁷⁴ Children are particularly vulnerable to exposure to PFAS because exposure has been shown to lead to reduced antibody responses from vaccination.⁷⁵ At present, there are only a few toxicology studies that have explored the combined effect of different PFAS, which is how the environment and humans are exposed to PFAS in the real world.⁴

4.3 Economic consequences

The costs of PFAS remediation will be high because it is difficult to remedy the large spread. The fact that the substances are stable, mobile and long-lived means that they contribute to continued exposure to both humans and the environment over a long period of time.⁵⁰ There is little knowledge about the long-term socioeconomic consequences associated with PFAS that have already been manufactured and released. In Europe, PFAS have been estimated to cause health-related costs of EUR 52-84 billion per year, which are probably underestimated figures.⁷⁶

5 Legislation

PFAS are regulated at a global level, as well as within the EU and nationally in Sweden. International regulations are implemented in Swedish legislation through regulations.⁶ Legislation regulates individual PFAS substances, but there is no overall legislation for PFAS as a group. Therefore, the Swedish Chemicals Agency together with authorities in Germany, the Netherlands, Denmark and Norway have submitted a bill to the European Chemicals Agency (ECHA) to regulate PFAS as a group and ban the manufacture and sale of the substances. Fluorine-free alternatives are currently available for many areas of use, and PFAS should, according to the proposal, only be allowed in uses that are critical to society where alternatives are lacking.³

5.1 International regulation

The Stockholm Convention⁷⁷ aims to reduce and prevent the release of hazardous substances into the environment and was adopted in 2001. It is an internationally binding agreement with requirements for the countries that have ratified the Convention. 152 countries have signed up and in the EU it was implemented through the Persistent Organic Pollutants Regulation⁷⁸, the POPs Regulation.⁶ The Stockholm Convention lists, inter alia, PFOS and PFOA, which means that the production and use of those substances must cease. There are proposals to include certain long-chain PFCAs in the Convention, which would entail more extensive restrictions compared to the EU's REACH Regulation.³

5.2 EU regulations

5.2.1 The REACH Regulation

In the EU, the REACH Regulation is the overarching chemicals legislation and the Candidate List is part of the REACH Regulation, which lists substances of very high concern and groups of substances.⁷⁹ If a product contains substances from the list, it may entail special requirements and about ten PFAS substances are on the list.³ The authorisation list in the REACH Regulation does not yet contain PFAS substances, which means that the substances are not subject to authorisation requirements in the EU.³ On the other hand, approximately 200 PFAS substances are included in the restriction list, which mainly regulates their use. It is under the REACH Regulation's restriction list that Sweden and the other countries have proposed that PFAS should be regulated as a group.³

5.2.2 Water Framework Directive

In order to protect and improve the aquatic environment in the EU, the Water Framework Directive was adopted in 2000 and it is supplemented by the Priority Substances Directive, among other things.⁸⁰ According to that, water administrations are required to examine 45 priority substances, including limit values, annual averages and maximum permitted concentrations.⁶ Some PFAS are included in the Priority Substances Directive and were also included in the new Drinking Water Directive.⁸¹ In Sweden, the Drinking Water Directive is implemented through the Swedish Food Agency's regulations on drinking water.⁸² The

Drinking Water Directive is a minimum directive, which means that countries have the opportunity to introduce stricter legislation nationally.⁶

5.3 National regulations

There is legislation that delegates the supervision of PFAS and it is a shared area of responsibility that involves different authorities. As a rule, central authorities provide supervisory guidance, but the regional authorities, mainly county administrative boards, can also have this role in relation to the municipalities, which often carry out the supervision. The supervisory responsibility includes developing support and guidelines for the operational supervisory authority. Regional authorities can carry out their own operational supervision, or delegate parts of it depending on legislation. The municipality is generally the operational supervisory authority, except for the activities of the Armed Forces.⁸³

The Swedish Chemicals Agency has compiled a list from various authorities of the limit and guideline values that apply to PFAS in Sweden⁸⁴, of which the values that are relevant to this report can be seen in Appendix I. Many of the limit values are based on a tolerable daily intake (TDI) for PFOS. This health-based guideline was updated in 2020, with a significant reduction from a TDI for PFOS alone of 150 ng/kg body weight to a TDI for the sum of 4 different PFAS substances of 0.6 ng/kg body weight.⁸⁵ The new guideline value may also lead to lower limit values for surface water and soil, for example.⁶

5.3.1 The Swedish Agency for Marine and Water Management's regulations

Environmental quality standards have been developed for the substances listed in the Priority Substances Directive. Through the Swedish Agency for Marine and Water Management's regulation 2019:25⁸⁶, these can be implemented as limit values in Swedish legislation and used to assess the chemical and ecological status of surface water bodies.⁶ To assess the chemical status, different limit values for PFOS in surface water and fish are used, while the ecological status is assessed using limit values for 11 PFAS substances (Appendix I). The Swedish Agency for Marine and Water Management has proposed new limit values for the ecological status and in the proposal the limit value for the 11 PFAS substances is replaced with a limit value for the sum of 4 different PFAS substances and a new limit value for fish muscle.⁸⁷ Since January 2019, environmental quality standards for surface and groundwater should be taken into account in assessments and permit cases, and if there is a risk of deterioration of status, activities or measures should not be permitted.⁶

Marine environment management is carried out in accordance with the Marine Environment Ordinance⁸⁸ with the aim of achieving good status in the marine environment. The state of the marine environment is assessed every six years using indicators in the Swedish Agency for Marine and Water Management's regulation 2012:18.⁸⁹ The assessment affects the action plan for the marine environment and the need for further measures. The concentration of PFOS and PFOA is included in the indicators.⁹¹ The concentration of PFOS and its derivatives in fish muscle is included in one of the indicators. In the latest assessment of the indicator, the threshold value for PFOS in the Swedish coastal waters was met, but a sharp reduction in the value has been proposed.⁹⁰ Knowledge about the impact of PFOS on Swedish marine

ecosystems needs to be developed, but it is clear that the substance is one of thousands of environmentally hazardous PFAS substances.⁹¹

5.3.2 Waste Ordinance

Waste to landfill is regulated in the Waste Ordinance and includes rules on the classification, management and transport of waste, as well as preventive measures.⁹² If waste is to be landfilled, certain requirements are listed in the Ordinance on the Landfill of Waste⁹³ as well as reception criteria in the Swedish Environmental Protection Agency's regulations 2004:10.⁹⁴ However, there are no limit values for PFAS in the criteria, but it must be possible to ensure that the requirements for each landfill class are met.⁶ At EU level, waste containing PFOS is regulated in the POPs Regulation⁷⁸, which the Swedish Environmental Protection Agency has interpreted to mean that waste must either be destroyed, disposed of or transformed depending on the concentration in the waste.⁹⁵ The EU also requires that PFOS and PFOA be tested every six months in discharges of water from waste treatment plants.⁹⁶ In Swedish legislation, this requirement was implemented in the Industrial Emissions Regulation in 2022.⁹⁷ The Environmental Code sets requirements for the discharge of environmentally hazardous activities to water. In order to obtain a permit, landfills that receive PFAS-containing waste must know what levels of PFAS may be present in the leachate and whether treatment is needed.⁶ The Swedish Environmental Protection Agency also requires that sampling takes place to investigate how nearby environments are affected.⁹⁵

6 Analysis and sampling

The commercially available technology used for sampling and analysis of PFAS has been developed over the past decade, with capacity going from a few to around 30 PFAS substances. Research laboratories can analyse and identify around 70 individual PFAS substances. The development has enabled analysis of PFAS in water, soil, animals, plants, sediments, sludge and products. At the same time, there is still a majority of PFAS substances that cannot be analysed in collected environmental samples.⁶

6.1 Remediation of contaminated sites

It is difficult to clean up areas contaminated with PFAS, due to the chemical properties, the persistence of the substances and the amount of PFAS that have been spread.⁹⁸ Techniques for soil and water remediation are under development, where a lot has happened in recent years. Landfill, incineration and soil washing are some examples of measures that can be taken for PFAS-contaminated soil.⁶ According to the POPs regulation, soil masses with high levels of certain PFAS substances cannot be landfilled, but must be incinerated.⁷⁸ PFAS-containing waste is only received by a few Swedish waste facilities and in 2018 it was noted that no waste facilities had treatment for PFAS in leachate, but this is under development with a number of pilot projects.^{11, 98}

Pumping and purification with filtration of PFAS-contaminated water is one of the techniques most commonly used to remediate contaminated water.⁹⁵ The contaminated water is then pumped out of the ground and passes through a filter system before being discharged again. There are different types of filters, and the choice of filter depends on the chemical properties and contaminant content of the water.⁶ IVL carried out a study of different treatment techniques for the treatment of PFAS-contaminated water from waste facilities where carbon filters, ion filters and foam fractionation showed the most potential.⁹⁸ See also Table 2. Newer methods such as sonochemical degradation, electrochemical treatment and chemical oxidation have also been studied. Both international and Swedish projects have been carried out on barrier technology where contaminated groundwater is treated *in situ* (on site). A material that binds PFAS is placed vertically in the ground to prevent the spread of PFAS with groundwater.⁶

Table 2. *Different treatment techniques for PFAS-contaminated water.*

Purification technology	New/Old	Technique	Advantage	Disadvantage
GAC (granular activated carbon) ^{4, 6}	Old (over 15 years old for PFAS treatment)	Filter	Effective for purification of long-chain PFAS	Can generate large amounts of waste, less suitable for high levels of short-chain PFAS
Ion exchangers ⁴	Old technology, new for PFAS treatment	Filter	Can filter a wide variety of PFAS	Other contaminants may affect the filter, pre-treatment may be required
Surface Active Foam Fractionation (SAFF) ^{4, 99}	Old technology, new for PFAS treatment	Bubbles from the bottom bring PFAS to the surface – foam can then be removed from the surface	Utilizes the properties of the substance, effectively purifies the water from long-chain PFAS	Research is underway on how the technology can better purify short-chain PFAS

7 The municipality's responsibilities and opportunities

Many environmental problems have the sea as their final destination and coastal municipalities need to deal with these, despite the fact that the problems often extend over several levels and start on land. Until stricter regulation and control of the substances are in place, municipalities have the opportunity to deal with PFAS in different ways.

7.1 The municipality's disposal and responsibility

The municipalities' broad operational areas entail several opportunities to work with PFAS issues in different ways. A general description of areas where the municipality has the power to act can be found in Table 3.

Table 3. Overview of municipal disposal areas of relevance to PFAS.

Activity	Example	Responsibility
Supervision	The municipality exercises supervision linked to ports, rescue services, agriculture, industries and other activities, among other things.	Relevant committees
Spatial planning	Physical space in plans for measures as well as location of new activities with regard to the problem.	Relevant committees
Procurement and purchasing	Procurement requirements on, for example, materials and chemical content for goods and services, requirements on the company's own organisation regarding choices and purchasing.	Relevant committees and companies

Operation of services	Operation and maintenance of: • Public buildings and premises, sports facilities, playgrounds. • Streets, parks and coastal areas. • Port operations and small boat operations. • Facilities for stormwater, wastewater and waste. • treatment plants, waste collection and waste management.	Relevant committees, and companies
Communication, collaboration and behavioural influence	Information for the general public, organisations, associations and companies, as well as information for young people via schools and preschools. Targeted campaigns.	Relevant committees and companies
Strategic work	Specific projects on PFAS (e.g. mapping of potentially contaminated areas, cooperation with coastal farmers) Chemicals plan and waste plan. Coordination and collaboration.	Relevant committees
Environmental monitoring	Sampling and investigations	Relevant committees

7.2 Examples of action

There are many opportunities for measures and changes that a municipality can implement to prevent the use and spread of PFAS, see Table 4.

Table 4. *Proposals for measures, activities and changes to prevent and manage the emergence and spread of PFAS within municipalities' areas of control.*

Proposed measures for the municipalities' work against PFAS pollution		
WATER AND SWEAGE	Discharges and incoming water	
	New technology	Filters in wastewater treatment plants. Filter leachate at landfills.
	Information	Campaigns aimed at the general public and operators.
	Infrastructure	Requirements for treatment of outgoing wastewater and runoff from landfills, delay and treatment of stormwater, reduced number of overflows, upstream work.
	Sludge	Requirements to analyse for PFAS.
SUPERVISION	Emissions and prevention	
	Information	For businesses and developers, the upstream work in all aspects is important (upstream in the catchment area and upstream in the emission hierarchy). Inform about PFAS sea foam before the bathing season, inform residents who grow their own vegetables near the coast, inform about antifouling paint, inform coastal farmers, inform residents with their own wells near the coast.
	Guidance	To industries, agriculture, marinas and other businesses. Handling that gives rise to the spread of

		PFAS can be noted. Information of inappropriate materials or products. Requirements for purification and design regarding the best available technology. Can be added to existing supervisory guidance.
	Permits and exemptions	In connection with the municipality receiving referrals, consultations or applications for permits or exemptions, a position/views/conditions can be provided regarding measures or activities that release or risk releasing PFAS.
	Injunction or clarification of existing prohibitions	Inspection and injunctions in case of inappropriate handling, inappropriate materials or products, and inadequate protective measures. Ordering the collection and disposal of contaminated water. Requirements for small boat facilities and analysis of PFAS in flush water, information about PFAS paint and alternatives, requirements for analysis of wastewater and sludge.
	Special focus	Wastewater discharges, coastal agriculture, beaches, runoff from landfills, areas where the rescue services have been operative, small boat operations, requirements for analysis of sludge (can also be added to existing control plan).
	Environmental monitoring	Land, water, animals and plants.
STRATEGY	Coordination, procurement, spatial planning and information	
	Procurement requirements	Relevant requirements are set for the municipality's own procurements (construction, facilities, care and operation, cleaning and chemical products (firefighting foam), furniture, toys, pesticides).
	Purchase requirements	For the municipality's own operations. Follow-up should take place in the annual report/environmental report.

	Spatial planning	Conditions for the appropriate location of businesses, infrastructure or residential areas so that the risk of spreading PFAS is minimized. Physically enable requirements to be set for the design of new activities and infrastructure. For example, designating suitable areas for snow and debris management, enabling appropriate stormwater management, restricting access/preventing the use of contaminated coastal farmland.
	Waste plan	Procedures for facilities that contain materials that can cause emissions of PFAS, can be added to existing routines, may require updating of waste plans and/or regulations.
	Information	Campaigns, materials, website aimed at the general public, schools and other businesses, officials, operators, businesses, politicians.
	Coordination/ collaborations	Water and sewerage, landfills, municipal companies, administrations, other authorities, universities and colleges, organisations, farmers.
	Material assessments for goods and services	For the municipality's various activities and for procurement, competence is required to make material assessments. This should also be required of contractors and companies from which the municipality buys goods and services. This can be, for example, for indoor and outdoor facilities, disposable products, wear and tear products.
	Circular economy/systems	Phasing out PFAS with economic benefits for other materials due to the unique properties of the substance. There are proven substitutes for many areas today. The PRIO tool on the Swedish Chemicals Agency's website gives companies the opportunity to identify and replace PFAS from their articles or products. ¹⁰⁰
CARE AND OPER	Phase-out, emission control and material management	

	Infrastructure	PFAS-free products, e.g. Plastic products
	Emission control programme	Wastewater, leachate, relevant activities and industry
	Replacement of materials	Chemical products, antifouling paint, fire extinguishing foam, PFAS-free workwear
	Technical equipment	When PFAS-free alternatives are available for electronic products, etc., disposal of old technical equipment.
	Collection	Collection and finishing of: • Wastewater from wastewater treatment plants • Leachate from landfills • Contaminated sludge • Bilge water
	Painting streets and facades	Paint without PFAS

8 What is happening in Swedish municipalities and other parts of the world?

8.1 Kungälv

PFAS was discovered in 2021 in one of Kungälv's waterworks during an extended control survey of drinking water that the municipality conducts once a year. PFAS were discovered in a water source that supplies Marstrand with drinking water and an extended investigation was carried out to locate the source of the contamination. The Armed Forces have historically had operations at Marstrand, but only used the area as a storage place and the municipality is investigating whether the rescue services could have contributed to the pollution via extinguishing missions. A survey of PFAS occurrences is underway in the municipality, but the source of the contamination in Marstrand's water source is still unclear.

Sampling in Marstrand's waterworks has also shown varying PFAS levels in the various process steps in the plant, which indicates an internal contamination. The municipality is investigating where the source of PFAS in the waterworks comes from. Marstrand's water source is relatively close to the sea, but it is several meters above sea level. It is still uncertain whether elevated PFAS concentrations could be explained by the addition of sea foam in the quarry. They want to control this and synchronize sampling with autumn storms that could potentially contribute contaminated PFAS sea foam to the water source. The municipality also wants to expand its environmental monitoring to sample PFAS on land (Personal communication, M HübINETTE 2024–10).

8.2 Ängelholm

In Ängelholm municipality, the PFAS issue is nothing new. The municipality has appointed an administrator who only handles PFAS issues. The former air force wing was active between the years 1940–2002 and has caused PFAS contamination of groundwater, surface water, soil, sediment and biota with ongoing spread in groundwater and surface water. In addition to the air force wing, PFAS are also found in other areas of the municipality with no known historical emissions. During development and within individual projects from government assignments, soil and water have been sampled for PFAS contamination. The mapping of potential PFAS-contaminated sites has been carried out with the help of documentation from the Swedish Civil Contingencies Agency and can in turn inform developers about where further sampling is needed. The sampling has contributed to more knowledge about the spread of PFAS in the municipality. When it comes to the municipality's environmental monitoring, PFAS are not included, but there are plans to take samples in surface watercourses within the municipality as a limited project.

The municipality, on the other hand, cannot make demands on the historical activities of the Armed Forces, but has the opportunity to comment. The Armed Forces have a control program for drinking water in individual wells in the vicinity of the former air force wing. One

of the water sources with elevated PFAS levels was used by, among others, a farmer whose cattle have been drinking from the contaminated water for a long time. The question of how the animals had been affected was raised and the County Administrative Board, which is the supervisory authority, was involved. Sampling of the animals was paid for with funds from the Swedish Environmental Protection Agency, through the Swedish Food Agency. This was a unique and an early case in Sweden where the animals drank water with known PFAS levels and the analysis results showed elevated PFAS levels in some of the animals. These animals were therefore not allowed to be slaughtered at the planned time. The municipality has not carried out sampling of PFAS in marine or coastal areas, but has commented to the Armed Forces that sampling of Skälderviken should be carried out. Coastal pastures are a potential problem area identified by the municipality, but they are few and there are currently no coastal grazing animals. Therefore, it is not currently a priority issue, but it is under monitoring (Personal communication, K Andersson 2024–10).

8.3 Sweden's PFAS Network

In 2014, the Swedish Chemicals Agency and the Swedish Food Agency started an open network in Sweden for everyone affected by the PFAS problem. To be able to exchange knowledge and experiences but at the same time to work out solutions to the PFAS problem and prevent future problems is the purpose of the network. It consists of government agencies, county administrative boards, municipalities, companies, consultants and researchers who meet twice a year.¹⁰¹

8.4 Denmark

In connection with an investigation of an old landfill located in the municipality of Lemvig on the west coast of Denmark, high levels of PFAS were discovered in soil and water. An investigation was carried out by the regional authority of the area, which is responsible for old pollution sites and landfills. The Danish equivalent of the Swedish Environmental Protection Agency was informed of the find by the municipality of Lemvig. The municipality was then given the task of investigating whether there was a historical or contemporary point source of the pollution. The municipality convened a special group of experts to investigate the problem.

Sand from beaches, soil, high groundwater, vegetation, berries, wild animals and seawater was examined and no point source could be found. On a windy field day, however, sea foam was discovered along the beach. Samples were taken of the foam, which turned out to contain high levels of PFAS. After the discovery, the Danish Environmental Protection Agency decided to analyse bathing water along the Danish coast and health authorities were contacted about the health risks of the sea foam. The National Food Agency was consulted regarding the consumption of food from the area. The study resulted in follow-up work with several actors to better understand the spread of PFAS via sea spray aerosols.

8.5 Netherlands

Like Denmark, the Netherlands has started investigating PFAS in coastal environments. In the municipality of Veere, which is located along the country's southwestern coast, coastal soil surveys have also been carried out with regard to the spread of PFAS via sea spray aerosols.

The studies measured elevated PFAS levels up to 500–600 meters inland compared to soil samples further from the coast. External factors such as what nature looks like, soil type and the content of soil organic matter seem to affect this spread. If the soil has a high proportion of organic matter, it tends to have a higher concentration of PFAS in the upper layers of the soil. After the study, the spread of PFAS within the municipality was mapped.

One of the biggest problems in Veere municipality is that many residents grow their own vegetables and fruit, either in their own gardens or in municipal allotments. Residents have expressed concern about PFAS in home-grown food. Limit values for PFAS in soil exist, but not all of them are legally binding. The result of the municipality's soil survey is that it is safe to live and have a small cultivation in one's own garden. Local farmers have also expressed their concern about the spread of PFAS, as grazing animals in nearby municipalities have been found to have high levels of PFAS. As a result, coastal grazing animals within the municipality are being evaluated.

Another problem that the municipality has encountered is that excavated material from the area often contains PFAS levels that are above the limit values for soil. Since remediation methods are not a feasible option, the municipality must develop a policy that makes it possible to reuse part of the soil, as long as it does not pose a risk to the environment and people. Other ways in which the municipality works with the PFAS issue is through a PFAS network, where relevant actors within the county meet every six weeks to exchange knowledge and experiences. The municipality of Veere is also part of an advisory committee that makes recommendations on research areas to the national government. Current research in the Netherlands will focus on the effects of PFAS spread via sea spray aerosols on the environment and health (Personal Communication, A Eijke 2024–12).

9 Challenges and the way forward

The issue of PFAS is complex and extends from the global level down to the local level. The spread does not follow geographical boundaries and can accumulate far from the sources. Legislation, preventive measures and research are important components in dealing with the problem.

9.1 Upcoming changes

The legislative proposal to the EU to regulate and ban PFAS as a group of substances instead of individual substances was submitted in March 2023 and is still being processed in 2025 by ECHA.¹⁰² Changes to the EU Wastewater Directive came into force on 1 January 2025 and include systematic PFAS monitoring in wastewater.¹⁰³ This is to be implemented in Swedish legislation. In Sweden, new and lower limit values for drinking water will come into force on 1 January 2026.⁸² The Swedish Agency for Marine and Water Management has proposed new limit values for PFAS that assess ecological status, and these are expected to enter into force in 2025.⁸⁷ We are continuously gaining more knowledge about PFAS and the consequences of the substances, and the problem is increasingly highlighted by various actors. Denmark has invested DKK 404 million in a PFAS action plan that will prevent, limit and treat PFAS pollution over a two-year period.¹⁰⁴

9.2 The way forward

It is important to stop both the use and production of PFAS where this is not of importance to society. There are some uses, for example in medical devices, where there are currently no alternatives available and where PFAS fulfil an important function¹⁰⁵. Research and development are needed to replace these persistent substances with alternatives that do not pose a danger to society. It is both costly and complicated to remediate areas with elevated PFAS levels, and therefore the supply of substances to the environment needs to be reduced and preferably stopped completely. While waiting for stricter legislation and the phasing out of PFAS, the work of municipalities will be an important part of protecting people and the environment.

What can your municipality do?

- Identify and map sources and routes of spread of PFAS in the municipality
- Integrate PFAS contamination into municipal governing documents
- Update supervisory guidance
- Communicate to and collaborate with other local actors and operators
- Review material options and procurement options
- Inform the public and industry

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II Attachments

Appendix I. Swedish guideline and limit values for PFAS (processed from the Swedish Chemicals Agency⁸⁴).

Class	PFAS 4	PFOS	PFAS 11	HaV's new proposal PFAS 4	Authority/legislation	Type of value	What does the value assess
<i>Drinking water</i>	0.004 ug/l	-	-	-	LIVSFS 2022:12	Legally binding limit value from 1 January 2026	Safe content for drinking water
<i>Coastal waters and waters in transitional zones that are bodies of drinking water</i>	-	-	Maximum permissible concentration 0.09 ug/l	0.004 ug/l	HVMFS 2019:25	Legally binding value for the Swedish Water Agency (PFAS 11) Becomes legally binding, proposed to apply no later than March 3, 2025 (PFAS 4)	Ecological status criterion
<i>Other surface waters (Coastal waters and waters in transition zones)</i>	-	Annual average 0.00013 ug/l	-	-	HVMFS 2019:25	Legally binding limit value for the water authority	Chemical Surface Water Status Criterion
<i>Other surface waters (Coastal waters and waters in transition zones)</i>	-	Maximum value 7.2 ug/l	-	-	HVMFS 2019:25	Legally binding limit value for the water authority	Chemical Surface Water Status Criterion
<i>Fish muscle</i>	-	-	-	0.077 ug/kg wet weight	HVMFS 2019:25	Becomes legally binding, proposed to apply no later than 3 March 2025	Ecological status criterion
<i>Fish muscle</i>	-	9.1 ug/kg wet weight	-	-	HVMFS 2019:25	Legally binding limit value for the water authority	Chemical Surface Water Status Criterion

