detritus | Multidisciplinary Journal for Circular Economy and Sustainable Management of Residues

CISA

ENVIRONMENTAL LAW ISSUES REGARDING PFAS POLLUTION IN WATER AROUND LANDFILLS IN SWEDEN

Malin Johansson [1,*], Maria Pettersson [1] and Jurate Kumpiene [2]

[1] *Department of Social Sciences, Technology and Arts, Luleå University of Technology, Sweden*
[2] *Department of Waste Science and Technology, Luleå University of Technology, Sweden*

Article Info:
Received:
11 January 2024
Revised:
6 March 2024
Accepted:
3 April 2024
Available online:
25 May 2024

Keywords:
Environmental law
PFAS
Landfills
Leachate

ABSTRACT

In this paper, the regulatory framework for PFAS is addressed, using the traditional legal method to analyze the rules and structures of existing laws and regulations in Sweden. The aim is to analyze and problematize the legal situation regarding PFAS in water around landfills, with a focus on leachate. The starting point is the updated risk assessment of PFAS and the requirements for a non-toxic and healthy environment. The study shows strengths and weaknesses with the environmental legal framework for PFAS contamination at landfills in Sweden. Four central problems have been highlighted: (1) production: waste containing PFAS continues to be sent to landfills; (2) old landfills that are not in use but pose a high risk of spreading PFAS; (3) landfills in operation, which comply with current regulations but have large concentrations of PFAS in leachate (and surrounding water); and (4) PFAS propensity for long-range dispersal. The revised health-based guideline from the European Food Safety Authority underscores the heightened danger of PFAS, emphasizing the need to minimise the risk of long-term exposure. It takes time to implement changes to the legal system. While it is possible to regulate purification and permitted levels of PFAS in leachate through permit conditions, this opportunity is rarely used. A large responsibility therefore rests on the authorities responsible for the licensing of landfills to align the individual permits with up-to-date scientific knowledge on PFAS risks.

1. INTRODUCTION

The top step in the European waste hierarchy is preventing the generation of waste and the last step is disposal, including landfilling (Directive 2008/98/EC, Article 4). This means that landfilling should be considered as the last resort for managing waste, limited to what cannot be further valorised within the Circular Economy concept. Despite this, landfilling is still the main method of handling waste in large parts of the world; it is seen as a simple and cost-efficient way to dispose of waste. On the other hand, when the Circular Economy principle is effectively applied, hazardous substances contained in the original products may accumulate both in the recycled materials and in residues disposed of in landfills, including PFAS (Cossu et al., 2020; Pivato et al., 2024). For this reason, the design of the landfill, in line with the principle of environmental sustainability, plays a crucial role in reducing the risk of environmental pollution and its harmful effects on human health (Grossule and Stegmann, 2020). Although strict requirements are often placed on active landfills, the many older landfills pose a great risk of pollution to soil, water, and air (SGI, 2011).

In Sweden, 4.4 million tons of waste (excluding extractive waste) were landfilled in 2020, which is an increase of 300,000 tons compared to 2018 (SEPA, 2022:36). Since the beginning of the 1990s, Sweden has worked diligently to select and promote other treatment methods to reduce landfilling, including material recycling with easily accessible recycling centers, as well as clear guidance for municipalities to reduce the amount of waste. As a result of stricter legislation and a series of bans on disposal of certain types of waste introduced in the 21st century, a large part of the active landfills in Sweden have been closed, and most of them will be covered by 2030. The materials used for the final coverings are layered to, among other things, prevent rainwater from seeping through and getting contaminated (Swedish Waste Management, 2022:3; 2023). There are currently 370 landfills in Sweden that submit environmental reports[1], and about 6,700 landfills are registered in the EBH-portal[2] (Miljösamverkan, 2022:8). However, the closed landfills continue to affect their surroundings for a very long time (SGI, 2023).

Per- and polyfluoroalkyl substances (PFAS) are a collective name for a group of highly fluorinated, industrially produced, and environmentally hazardous substances that

* Corresponding author:
Malin Johansson
email: malin.3.johansson@ltu.se

https://doi.org/10.31025/2611-4135/2024.18382

have been used in large-scale production since the early 1950s (KEMI, 2021:9). There are over 12,000 different PFAS structures that have been identified (EPA, 2021), and of these, roughly 4,700 have been inventoried so far (OECD, 2018:16). Since many PFAS are grease-, dirt-, and water-repellent, it makes them very useful in products like textiles, lubricants, and food packaging materials. Other PFAS also have surface-active properties that make them useful in, for example, cookware, cleaning agents, paints, ski wax, and cosmetics (KEMI, 2015:32-49). PFAS are very effective, and therefore only low concentrations are needed to achieve the desired function in the product (KEMI, 2015:66). Due to the strong bond between carbon and fluorine, PFAS are extremely persistent and do not fully degrade under natural conditions. This means that PFAS remains indefinitely in the environment in some form (KEMI, 2021:16).

Perfluoroalkyl sulfonic acids (PFSA) and perfluorocarboxylic acids (PFCA), such as perfluorooctane sulfonate (PFOS) and perfluorooctanoic acid (PFOA), respectively, are the PFAS that have mainly been studied in the last 20 years (KEMI, 2021:13). Thus, for the majority of PFAS and their effects on health and the environment, there is a lack of knowledge. There are, however, strong reasons to consider all PFAS as harmful to health (Bonato et. al., 2020; Lohmann et. al., 2020; Fenton et. al., 2021). Studies show that PFAS may affect reproduction, the immune system, birth weight, cholesterol levels in the blood, and cause cancer (Bonato et al., 2020; EFSA, 2020:3-9; ATSDR, 2021 Ch. 2; Fenton et al., 2021; Racz and Kempisty, 2021:3). Although available epidemiological studies show this correlation between exposure to PFAS and the mentioned health risks, it has not yet been possible to establish a cause-and-effect relationship for most of these health risks (ATSDR, 2021:26). Today, PFAS are found everywhere in the environment all over the world, and almost all people have PFAS in varying degrees in their bodies[3] (KEMI, 2021:9).

Many PFAS have high water solubility, which, together with their persistence, gives them high mobility and a great potential for long-distance transport by water. Some PFAS (e.g. fluorotelomer alcohols (FTOHs), perfluorobutanoate (PFBA)) can be released into the air from materials, production processes, incineration, wastewater treatment, and landfills (Ahrens et al., 2011; Hamid and Li, 2016; MPCA, 2022; Björklund et al., 2023); and spread long distances through the air, which constitutes an important spread path to soil and surface water globally. This means that PFAS, via atmospheric deposition, can also be added to areas that otherwise have no influence from civilization or direct sources, like arctic environments. PFAS can enter groundwater by precipitation, irrigation, or flooding when they are present in the soil. In groundwater, the contaminants, due to their relatively high tendency to dissolve in water, can spread over long distances. Emissions to surface water can occur via runoff from contaminated areas, contaminated groundwater, emissions from, for example, extinguishing operations, treatment plants, landfills, or atmospheric deposition (KEMI, 2021:34-36; Racz and Kempisty, 2021:7-9).

PFAS has accumulated in both active and closed landfills due to decades of consumer use and subsequent disposal of products, industrial waste, and sludge containing PFAS (Bolan et al., 2021:120). Knowledge about the composition, concentrations, and waste streams of PFAS in Sweden is often inadequate because only a few percent of the Swedish landfills have been investigated regarding PFAS. As a result, PFAS are spread to surrounding water and soil, where they pose a threat to humans and the environment for a long time to come (Miljösamverkan, 2022:3 and 8).

The aim of this paper is to analyze and problematize the regulations regarding PFAS in water near landfills, with a focus on leachate, in light of an updated risk assessment of PFAS and the requirements for a non-toxic and healthy environment. The study will highlight the strengths and weaknesses of the environmental legal framework for PFAS pollution at landfills in Sweden.

After the introduction, data on PFAS from Environmental Cooperation Sweden (Swe: Miljösamverkan Sverige)[4] is presented to give an overview of PFAS findings at landfills in Sweden. Thereafter, the revision of the health-based guideline value from the European Food Safety Authority is briefly summarized to show a changed view of the risk assessment of PFAS. This is followed by an account of the regulation of PFAS on the international and European Union (EU) level, with a particular focus on waste (landfill) and water legislation. Lastly, the results are discussed and conclusions are presented.

2. MATERIALS AND METHODS

The analysis is based on a qualitative legal review of the regulations for PFAS. A traditional legal method has been applied, which in short means searching for a solution to a legal problem by analyzing and interpreting current law based on the generally recognized sources of law (Kleineman, 2018:21; Sandgren, 2009:118). The starting point for the analysis has been a review of the international regulation of PFAS. As an EU member state, Sweden is obligated to fulfil the requirements of secondary EU law (i.e., directives, regulations, and decisions), which means that certain areas of Swedish legislation are strongly influenced by EU law and, in some cases, directly transferable. This applies in particular to the waste and water legislation, as these matters are to a large degree harmonized at the EU level, thus limiting the possibilities for strictly national legislative solutions. Consequently, the central focus of the analysis has been relevant EU regulation, which has been followed by national legislation. To gain a greater understanding of the problem and the threat that PFAS in landfills poses to human health and the environment, materials from various authorities and organizations have also been studied.

3. PFAS UPDATE

3.1 Environmental Cooperation Sweden

With an emphasis on PFAS in leachate, Environmental Cooperation Sweden established a case manager support program for PFAS in landfills in January 2022. Measurement data on PFAS in leachate from landfills, as well as in surrounding groundwater and surface water, was collected

from 165 Swedish landfills in different phases. Leachate data was obtained from 117 landfills. The number of PFAS analyzed varied between 1 and 34. The investigated landfills had not installed treatment technologies to effectively remove PFAS. The general methods that existed for removing pollution were, for example, sedimentation ponds and wetlands. PFAS were present in measurable levels in all leachate samples, even after existing treatment methods. Since PFAS hardly breaks down, existing treatment methods are not sufficient to effectively remove all PFAS (Miljösamverkan, 2022:9 and 12).

Furthermore, the results showed that surface water and groundwater adjacent to the landfills contained PFAS, often in concentrations that exceeded the Water Authority's assessment criteria (environmental quality standards for water) for PFAS-11 and PFOS. Groundwater and surface water bodies upstream of the landfills also contained PFAS. This may be because the spread of PFAS from landfills is greater than estimated and/or that there are uncertainties regarding the direction of the water flow. A more likely reason is however that there are other sources of PFAS within the catchment area. High concentrations of PFAS found in groundwater and surface water were often also found in high concentrations in leachate (Miljösamverkan, 2022:13). Figure 1 shows some highlights of the project findings.

PFAS with the highest concentrations in leachate were PFBA, PFBS, PFPeA, PFHxA, and PFOS, with a maximum concentration that varied between 22800 and 74600 ng/L and a mean value that varied between 427 and 1242 ng/L. The most common PFAS in leachate were PFHxA, PFOA, PFOS, PFPeA, and PFHpA, with a detection frequency between 96 and 99%, and PFHxS, PFBS, and PFBA had a detection frequency between 89 and 94%. At least one PFAS was present in 83–84% of all examined surface and groundwater. With a detection frequency of 53–71%, eight PFAS—PFOS, PFOA, PFHxA, PFBA, PFHxS, PFHpA, PFPeA, and PFBS—were discovered in more than half of the surface and groundwater samples analyzed (Miljösamverkan, 2022:10-13).

3.2 European Food Safety Authority guideline value

The European Food Safety Authority (EFSA) has previously carried out a risk assessment of PFOS and PFOA. In 2008, a so-called tolerable daily intake (TDI) was determined, based on animal studies, of 150 ng/kg of body weight and day for PFOS and 1500 ng/kg of body weight and day for PFOA. The TDI corresponds to the amount of these substances that a person can ingest every day throughout their life without risking any impact on health (EFSA, 2008:2-4).

According to EFSA's 2020 intake estimates, the weekly exposure of the European population to per-weekly PFAS exposure ranges from 3 to 22 ng/kg of body weight. Fish, fruit, and eggs were the foods that contributed the most to exposure to PFAS. In areas with PFAS-contaminated water, exposure to PFAS via drinking water can be a significant source (EFSA, 2020:39 and 147).

EFSA has updated its risk assessment of PFAS based on epidemiological studies and their effect on the immune system. In the latest evaluation from 2020, a joint tolerable weekly intake (TWI) is specified for four different PFAS: PFOA, PFNA, PFHxS, and PFOS. The assumption is that these PFAS have similar properties and are equally toxic. The evaluation states an overall TWI of 4.4 ng/kg of body weight per week. The TWI value is the exposure level one should maintain throughout one's lifespan (EFSA, 2020:7-8).

4. RESULTS

4.1 Global regulation on PFAS

The first reports on the risk and harm of PFAS came in the early 2000s (Giesy and Kannan, 2001; Hansen et. al., 2001). Since then, techniques have been created and are still being developed to, among other things, detect lower concentrations of PFAS in water. This has created a greater awareness of the problem with PFAS.

At the global level, the relevant instrument is the 2001 Stockholm Convention on Persistent Organic Pollutants ('Stockholm Convention'). The convention aims to protect human health and the environment from the harmful ef-

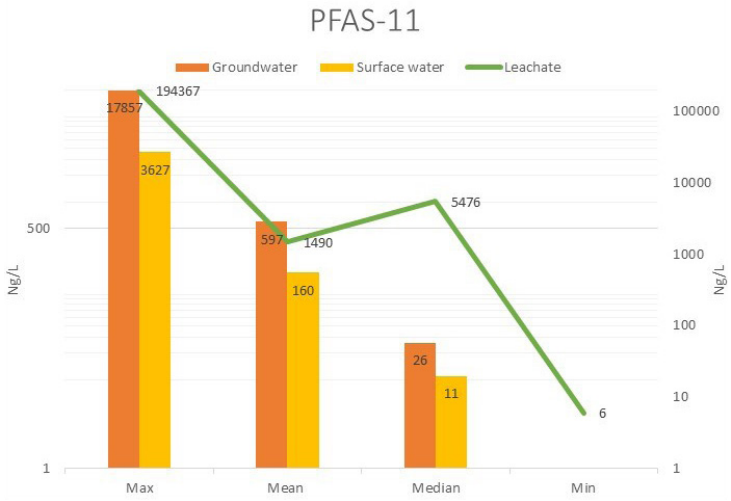

FIGURE 1: PFAS-11 found in leachate, groundwater, and surface water (Miljösamverkan, 2022:10 and 13).

fects of persistent organic pollutants (POPs) by prohibiting, phasing out, or limiting the use and production of listed substances, but also to limit or eliminate, where possible, emissions of unintentional byproducts. In addition to production and use, the convention also covers waste management and environmental monitoring (UN, 2001; UNEP, 2020). PFOS, its salts, and related substances were added to the annex of the convention in 2009 (UNEP, 2009). In 2019, the annex was updated based on new assessments on PFOS, adding PFOA, its salts, and related substances to the list (UNEP, 2019a; UNEP, 2019b). The latest PFAS addition to the convention was made in 2022 with perfluorohexanesulfonic acid (PFHxS), its salts, and related substances (UNEP, 2022). Compliance with the convention would imply a global phase-out of these three PFAS and their substances. Considering the risk profile and the risk management evaluation of PFAS, we can expect more PFAS to be added to the list in the future. Already, there is a proposal to include long-chain (C9–C20) perfluorocarboxylic acids (PFCAs), their salts, and related compounds in the Stockholm Convention Annex (UNEP, 2021).

4.2 EU regulation on PFAS

The first EU legal act relating to one PFAS substance was adopted in 2006 with regard to restrictions on the marketing and use of certain dangerous substances and preparations. Even if PFOA were suspected to have a similar risk profile, it was PFOS that were first regulated to be restricted based on the assessment that PFOS are persistent, bioaccumulative, and toxic to mammalian species (Directive 2006/122/EC, Recitals 1 and 7).

The Stockholm Convention's requirements for limiting PFOS, PFOA, PFHxS, and substances that can be broken down into these substances have been introduced into EU legislation through the Regulation on Persistent Organic Pollutants ('the POPs Regulation'). The POPs Regulation aims to protect human health and the environment by eliminating, phasing out, or limiting the production and use of POPs, as defined in the Stockholm Convention or the Protocol to the 1979 Convention on Long-Range Transboundary Air Pollution on Persistent Organic Pollutants (CLRTAP) (Regulation (EU) 2019/1021, Article 1 and Annexes; Regulation (EU) 2022/2400). Since PFOS, PFOA, and PFHxS are included in the POPs Regulation, they are prohibited to manufacture, place on the market, and use within the EU, except for certain special exceptions, including use for laboratory-scale research. The objective is to control waste that contains or is polluted by POPs and to reduce, if at all possible, POP emissions. The aim and objectives of the regulation have been formulated with the precautionary principle in mind, which means that a lack of scientific agreement regarding the risk of damage caused by the POPs must not mean that precautionary measures are not taken (Regulation (EU) 2019/1021, Articles 1, 3, and 4; Regulation (EU) 2022/2400).

Producers or holders of waste must, as far as possible, avoid contamination of the waste with the substances listed in Annex IV of the regulation. To ensure that the POP content is destroyed or irreversibly transformed, contaminated waste must, in most cases, be disposed of or recovered quickly (Regulation (EU) 2019/1021, Article 7). It is the responsibility of each Member State to ensure that the production, collection, and transport of contaminated waste, as well as its storage and treatment, is carried out under conditions that protect human health and the environment (Regulation (EU) 2019/1021, Article 7(6); Directive 2008/98/EC, Article 17).

The presence of PFAS in waste is regulated by limit values (Regulation (EU) 2019/1021, Annex IV). Since November 2022, limit values for PFOA and PFHxS have been added to the annex following the addition of these substances to the Stockholm Convention (Regulation (EU) 2022/2400).

The POPs Regulation Annex IV shows a Low POP Content Level (LPCL), and Annex V shows a Maximum POP Content Level (MPCL). When waste contaminated with POPs is to be destroyed or irreversibly transformed, the LPCL is specified in concentrations, in mg/kg. For PFOS and its derivatives, the limit value is 50 mg/kg; for PFOA and its salts, 1 mg/kg; for PFOA-related compounds, 40 mg/kg; for PFHxS and its salts, 1 mg/kg; and for PFHxS-related compounds, 40 mg/kg (Regulation (EU) 2019/1021, Annex IV; Regulation (EU) 2022/2400). If the waste has a level between LPCL and MPCL, it can be stored permanently in a bedrock formation, salt mine, or landfill for hazardous waste, provided that the waste has been stabilized and a decision has been made by the appropriate national authority (Regulation (EU) 2019/1021, Annex V). In Sweden, the appropriate national authority is the Swedish Environmental Protection Agency (SEPA).

Exemptions from the regulations pertaining to the destruction or irreversible transformation of PFOA and PFHxS in accordance with the higher levels in Annex V may be requested if there is a lack of accessible technology and the application is environmentally appropriate. According to SEPA's interpretation, it is not possible to grant such a dispensation for waste contaminated with PFOS since the upper and lower limits for PFOS are the same. All waste containing more than 50 mg PFOS/kg dry matter must be destroyed or irreversibly transformed. This means that the waste must be handled in such a way that PFOS is not at risk of spreading further, e.g., through incineration. In this case, recycling or disposal methods are not allowed, as this may lead to further contamination of the waste. However, waste containing less than 50 mg PFOS/kg dry matter needs to be disposed of or go through recovery operations in a manner that is compatible with current EU regulations. In general, if the waste contains concentrations below the LPCL of the respective POP substance, it does not need to be destroyed or irreversibly transformed. The waste must instead be recycled or disposed of in a way that is compatible with the appropriate EU legislation and gives the best results for the environment (Regulation (EU) 2019/1021, Annexes IV-V; SEPA, 2023; SEPA, 2024).

4.3 Landfills and PFAS regulation

The main Swedish regulation on waste landfills is the Ordinance (2001:512) on landfilling. This ordinance was adopted to incorporate the requirements of the EU Directive 1999/31/EC on the landfill of waste in Swedish law. The latter aims to prevent, or where possible reduce, the

negative effects that landfills have on land, air, surface water, groundwater, and human health (Article 1). To support the EU's transition to a circular economy, the directive was amended in 2018 (Directive (EU) 2018/850, Recital 2). One goal of the directive is to limit the proportion of landfilled municipal waste to 10% by 2035 at the latest (Directive 1999/31/EG; Directive (EU) 2018/850, Articles 1 and 5(5)). A couple of key points in the directive are that Member States must implement national strategies to try to reduce the amount of biodegradable waste going to landfills; only waste that has been treated may be deposited; and landfill owners must apply for a permit, which, among other things, must include information on methods to prevent and reduce pollution (Directive 1999/31/EG, Articles 5(1), 6(a) and 7; Directive (EU) 2018/850).

After a landfill is closed, it continues to affect its surroundings for a very long time. To limit the leakage of leachate, EU requirements for the final landfill cover are, in Sweden, transposed into the Ordinance (2001:512) on landfilling. As an example, the final cover for landfills for hazardous waste must be designed so that the amount of leachate passing through the cover does not exceed 5 L/m^2 per year. It is the operator's responsibility to ensure that the limit is not exceeded. Landfills in operation must be protected against surface and groundwater entering the landfill (Swedish Ordinance 2001:512, Para. 23 and 31).

There are three categories of landfills. The division is based on the type of waste that is landfilled: hazardous waste, non-hazardous waste, and inert waste (Directive 1999/31/EG, Article 4; Swedish Ordinance 2001:512, Para. 7). A correct classification of the waste is important. To assess whether a waste has hazardous properties, Annex III to Directive 2008/98/EC on waste ('the Waste Framework Directive') is applicable (Swedish Waste Ordinance 2020:614, Ch. 2 Para. 2). When a waste contains a substance that is classified with at least one of the hazard class codes found in Annex III of the Waste Framework Directive, it shall be classified as hazardous waste. The substance PFOS is reproductively toxic (H 10), and the limit for when waste with PFOS content must be classified as hazardous is therefore set at 0.3% (3000 mg/kg). The limit for when a waste is classified as hazardous in terms of PFOS, PFOA, and PFHxS can thus be significantly higher than what follows from the requirements for destruction or irreversible conversion according to the POPs regulation (SEPA, 2023).

SEPA's regulations on disposal, criteria, and procedures for receiving waste at waste disposal facilities (NFS 2004:10)[5] contain acceptance criteria and limit values for waste that is deposited. The regulation currently has no acceptance criteria for any PFAS substance. However, before waste is deposited, the operator must have acquired as much knowledge as possible of the waste's composition, leachability, and other properties, as well as the effects of the waste in general and in the long term (Swedish Ordinance 2001:512, Para. 16).

Waste that contains pollutants that lack acceptance criteria must nevertheless be examined to assess whether it meets the landfill class in which it has been classified (NFS 2004:10, Para. 4). The limit values for PFOS, PFOA, and PFHxS, according to the POPs regulation, must therefore be taken into account when receiving waste at a landfill. There are no general guidelines on what requirements should be set for any substance in leachate that, after local treatment, is released to the recipient or is led to a sewage treatment plant. However, the landfill owner must have knowledge of the PFAS levels found in leachate leaving the landfill. Special precautions such as stabilization, covering of the masses, deposition in separate cells, etc. may be necessary. These measures must be assessed and tested in each individual case, in keeping with the precautionary principle. Conditions are set for each landfill during the permit assessment in accordance with the Swedish Environmental Code (SEC) (SEPA, 2023).

With the support of Ch. 9 SEC and the Swedish environmental assessment ordinance (2013:251) regarding environmentally hazardous activities and health protection, a permit for landfill operations may be granted. The application for a permit is assessed based on the general rules of consideration, according to which requirements for knowledge, caution and resource management can be set, and results in concrete conditions for landfill operations (Ch. 2 SEC). Common conditions include that leachate from the facilities must be collected and stored in ponds, and the impact of the emissions on the recipient must be controlled. Landfilling can also constitute water operations that, in connection with the design of landfills and the handling of leachate, may be subject to a permit or notification requirement following Ch. 11, s. 9 and 9a SEC. The leachate itself is considered waste (Swedish Ordinance 2020:614, Annex II).

There are currently only a few landfills that have conditions in their permits for the release of PFAS. According to Environmental Cooperation Sweden, there are only conditions or probationary conditions regarding PFOS for three landfills in Sweden. In these cases, the PFOS content in outgoing water must not exceed 80–100 ng/L. The project team currently assesses that around 20 ng/L of PFAS in outgoing leachate can be seen as a benchmark for when the supervisory authority should require an investigation of appropriate measures. However, an assessment should be made in each individual case. Lower levels may be appropriate for a particularly sensitive recipient, and higher levels may be acceptable under certain conditions (Miljösamverkan, 2022:26 and 35).

The situation is, however, largely characterized by the absence of clear guidelines for the authorities. On top of that, in the few cases where limit values have been set, there is disagreement regarding what the appropriate level is. An example is the judgement from 2021 of the Swedish Environmental Court of Appeal in case M 2164-19. The case concerned conditions for a landfill, where the County Administrative Board in Jönköping County demanded a limit value for PFOS of 20 ng/L to ensure that there is no deterioration of the status of the water body with regard to PFOS and the environmental quality standards (EQS) based on calculations of dilution in the recipient. In their judgment, the court issued provisional regulations stating that the PFOS content as an annual average may not exceed 80 ng/L in outgoing treated water.

In the event that no limit values are set, the supervisory authority always has the opportunity to issue injunctions and prohibitions that are needed in an individual case, with the support of Ch. 26 and Ch. 2 SEC. The supervisory authority could, for example, issue an injunction for control of a waste facility and its leachate.

For waste treatment facilities, there are requirements according to the EU's Best Available Technique (BAT) conclusions for waste treatment (Decision (EU) 2018/1147). These provisions are mainly implemented through the Swedish Industrial Emissions Ordinance (2013:250). According to the BAT conclusions, PFOS and PFOA in water discharges from waste treatment facilities must be monitored once every six months (Decision (EU) 2018/1147, Annex). The BAT conclusions apply in parallel with the requirements following the permit assessment. A specific BAT requirement is also enshrined in the SEC, which means that requirements regarding BAT can be set based on both the SEC (Ch. 2 Para. 3) and the BAT conclusions.

A number of Swedish sewage treatment plants receive leachate from landfills. The measures required for these plants are based on the requirements set according to the voluntary certification system Revaq[6]. Normally, leachate from landfills should not be connected to Revaq-certified sewage treatment plants; instead, the leachate must be disconnected, and reconnection is not permitted after the certificate is granted. To be allowed to maintain a connection to a certified sewage treatment plant, the disconnection must lead to the raw water protection being damaged or a recipient for the leachate being missing, at the same time as the leachate must be purified to an acceptable level according to the Revaq manual for assessment of leachate. So far, the manual only contains levels and tolerable allowances for PFOS[7] (Allmyr and Sternbeck, 2017:4, 8, and 12; Miljösamverkan, 2022:34).

4.4 Water and PFAS regulation

The EU Water Framework Directive (WFD) was adopted in 2000 and aims to protect and improve all water within the EU (Directive 2000/60/EC). The directive is supplemented by three subsidiary directives: The Priority Substances Directive (Directive 2013/39/EU), which specifies limit values and regulates 45 priority substances to be investigated in water management; the Groundwater Directive (Directive 2006/118/EC), containing criteria for assessing good chemical groundwater status and for detecting and reversing upward trends in the occurrence of contaminants; and the Drinking Water Directive (Directive 2020/2184). In Sweden, the WFD was introduced into Swedish legislation in 2004 through Ch. 5 SEC, the Swedish Ordinance (2004:660) on management of the quality of the water environment, and the Swedish Ordinance (2017:868) with county board instructions.

Based on the WFD, the Water Authorities[8] in Sweden have established EQS for the priority substances that are specified in the Priority Substances Directive, which only lists one PFAS, PFOS. The Swedish Agency for Marine and Water Management has, among other things, the task of protecting, restoring, and ensuring that fresh water and sea resources are used sustainably. In their regulation (HVMFS 2019:25), an EQS for PFOS in surface water is set to 0.65 ng/L as an annual average value (Annex 6), while for surface water that is a source of drinking water, there is an EQS for PFAS-11 at 90 ng/L (Annex 5(4)). These limit values are legally binding for the water authority's risk, status, and action assessments. Leachate is mainly formed by rainwater that infiltrates the landfill, but in old landfills, ground and surface water seep into the landfill and thus form leachate. If the soil beneath the landfill is unsaturated with moisture, such as in an inflow area, the leachate can infiltrate through the soil, and in this way, some contaminants are retained in the soil while others are transported further and risk contaminating the groundwater (SEPA, 2008:5).

When it comes to PFAS in groundwater, in 2016, the Water Authorities produced EQS for the total concentration of PFAS-11. At a concentration above 90 ng/L, the groundwater body was considered to have an unsatisfactory status. Already at 18 ng/L, i.e., at a concentration sum of 20% of the EQS, measures were to be taken to reverse the trend (SGU-FS 2013:2; Swedish Water Authorities, 2016). In 2022, the European Commission presented a proposal for a revision of the WFD, the Priority Substances Directive, and the Groundwater Directive with the aim of improving the protection of EU citizens and the environment by, among other things, enabling a faster process of inadequately managing chemical threats (European Commission, 2022). From March 2023, a new general threshold value for PFAS in groundwater applies within the Swedish water administration, which is based on the commission's proposal. In the Geological Survey of Sweden's regulation on mapping, risk assessment, and classification of groundwater status, it is established that the new general threshold value pertains to the weighted sum of PFAS-24 and is set at 4.4 ng PFOA equivalents/L. The threshold value means a total sum of all PFAS content after these have been individually converted to PFOA equivalents based on the substances' toxicity factors (SGU-FS 2023:1, Annex 3). This threshold value has no legal effect but will exist as support for the Water Authorities in their work. The guidelines decided by the Water Authorities for the sum of PFAS-11 are legally valid until 2027 at the latest when the Water Authorities next decide on threshold values (KEMI, 2023a:2).

At the end of 2020, a new directive (2020/2184) on the quality of water intended for human consumption was adopted. The goal is to protect human health from the harmful effects of all kinds of contamination of drinking water (Recital 2). Limit values for PFAS-20 were introduced in the directive (Annex III, Part B). Member States must have taken the necessary measures by January 12, 2026, at the latest to ensure that the drinking water is compatible with the new, legally binding limit values (Article 25). It is estimated that around 20 million people in Europe may be exposed to drinking water with higher PFAS levels than the new recommended limit values determined within the EU (KEMI, 2023b).

In the new drinking water directive, a parameter value of 100 ng/L is set for PFAS-20 (Directive 2020/2184, Annex I, Part B). This legislation entered into force in Sweden on January 1, 2023, and applies to municipal drinking water and drinking water from public and commercial business-

es (LIVSFS 2022:12, Para. 2). The Swedish Food Agency's previous, non-legally binding recommendations for drinking water referred to PFAS-11, with an action limit of 90 ng/L and an upper guideline value for when you should avoid drinking the water of 900 ng/L (Swedish Food Agency, 2021:10). Based on EFSA's statement from 2020, Sweden has now chosen to set a national guideline value of 4 ng/L for PFAS-4 and 100 ng/L for PFAS-21, applicable from January 1, 2026 (LIVSFS 2022:12, Annex 1). As a comparison, it can be mentioned that the Danish Environmental Protection Agency has chosen to lower the limit value to 2 ng/L for PFAS-4 (Danish Miljøministeriet, 2021).

In 2013, it was discovered that the drinking water for residents in Kallinge, in southern Sweden, and the surrounding area and the northwestern parts of Ronneby municipality were contaminated with high levels of PFAS. The contamination had spread from a nearby fire drill area to the ground, the groundwater, and on to the drinking water. The levels of PFAS measured in the drinking water were among the highest measured in the world, at 10,380 ng/L. A group of 165 people came together to sue the municipal water company for the health risks of living with high levels of PFAS in the blood. Ten years later, in December 2023, the Swedish Supreme Court announced that the municipal water company was responsible for personal injuries in the form of elevated levels of PFAS in the blood, which means physical deterioration of the body, and must therefore compensate the plaintiffs (Case T 486-23).

5. DISCUSSION

In this paper, we have highlighted the legal situation regarding PFAS in landfills. We have focused on the regulation of waste and water in Sweden. This includes an analysis of the functionality of the legislation when it comes to the management of PFAS in landfills in relation to the overarching goal of protecting human health and the environment.

When it comes to the specific legal regulations around PFAS and landfills, the study points to some central problems: (1) production, we continue to send waste containing PFAS to landfills; (2) old landfills, which are not in use but pose a high risk of spreading PFAS; (3) landfills in operation, which comply with current regulations but have large concentrations of PFAS in their leachate (and surrounding water); and (4) PFAS propensity for long-range dispersion. What we have concluded is the following:

The precautionary principle is a well-established principle that permeates both international, EU, and national law. The principle briefly means that precautionary measures must be taken when an activity poses a risk to human health or the environment. It goes along with the idea that it is "better to be safe than sorry" and entails that although scientific evaluations cannot assess the risk with certainty, precautionary measures should be taken to avoid a potentially hazardous effect of, for example, a product or process. Provided that measures taken are proportionate to the desired level of protection, it is not discriminatory and is consistent with previous measures in similar situations (Pettersson & Johansson, 2022). We do not have knowledge about all PFAS, but we do know that PFAS are persistent in the environment, bioaccumulative and that some may be toxic to humans and animals. Although PFAS may not cause acute problems, we know that long-term exposure implies a high risk of several serious health problems in humans. Despite this, so far, only three PFAS are banned within the EU. Moreover, there is no comprehensive legislation that covers all PFAS; instead, individual PFAS are regulated at different legislative levels. Often, when an individual PFAS is regulated, that substance is replaced with another unregulated PFAS. There are simply too many substances, and the process of deciding whether to add a substance to a restriction or ban list takes too long. In that way, the legislation has no effect when it comes to reducing the risk.

There are currently two EU proposals submitted regarding PFAS. One of the proposals concerns banning PFAS in fire-fighting foam (ECHA, 2022), and the other is a restriction proposal that intends to treat PFAS as a group and manage PFAS uniformly within the EU (ECHA, 2023). Fire-fighting foam containing PFAS has caused serious environmental contamination, both of soil and drinking water. The proposal to ban PFAS in fire-fighting foam would mean that no further PFAS are spread in that way. What remains is the problem of contamination that already exists and that needs to be managed. If we do not act, it is estimated that around 4.4 million tons of PFAS will end up in the environment in the next 30 years (ECHA, 2023). The proposal to treat PFAS as a group would prevent the problem of one substance replacing another as soon as one is restricted. The positive effects of PFAS restrictions are already noticeable, and the concentrations of PFOS seem to have decreased on the Swedish west coast. Studies from the national monitoring program for environmental toxins in biota showed a decrease in PFOS levels in herring liver at the sampling station Fladen during the period 2004-2016 (Bignert et al., 2017:286). However, even if PFAS are banned or restricted from now on, the problem of contaminated waste will remain for a long time. The waste that we have already generated will not disappear. We must thus both reduce the PFAS emissions that occur today and find ways to handle PFAS pollution from existing sources, such as landfills.

This brings us to the problem of environmental risks associated with old landfills that are not in operation. It is estimated that there are several thousand older landfills in Sweden that were closed before the current regulation came into force. These have been closed according to earlier, and much lower, requirements for landfilling or before requirements for protective measures even existed. As a result, the environmental protection surrounding these landfills is generally very low. As an example, there is no or only limited monitoring of leachate (SGI, 2014:13). The responsibility to inventory closed landfills and assess the risk to human health and the environment lies with the municipalities (NFS 2020:6, Para. 17). Although this work must be included in each municipality's waste plan, the pace of the inventory varies between municipalities because it can be costly, it requires commitment, and it is not clear how the risk assessment should be made or how the result should be implemented. Another issue concerns who can be held legally responsible for the remediation of a contaminated

area. Even if the starting point is the Polluter Pays Principle (PPP), it is in practice often complicated to, for example, determine who is the polluter, or to find the polluter. This will however not be discussed further here.

The previously set EQS for PFOS and PFAS-11 are exceeded in some water bodies today. This entails the risk that PFAS contaminates our ground and drinking water and that the problem may increase over time. This brings us to the problem of active landfills that comply with current regulations but that, despite this, still have high levels of PFAS in their leachate, which spreads to the surrounding waters. The regulation for PFAS in waste only regulates three PFAS so far, and the threshold for waste to be considered hazardous is high. As there are no national guidelines for treatment and permit levels for PFAS in leachate, it is difficult for the authorities to regulate PFAS in the operator's permit, although it has become more common for authorities to request measurements of PFAS in leachate and recipients. It is important to set requirements for supervision and control of PFAS, and the regulation needs to be both clearer and more uniform. These shortcomings point to the necessity of information regarding PFAS, including education, innovation, and voluntary measures.

The problems with PFAS contamination have gained increasing attention lately. In addition to the fact that the media has been diligent in reporting and informing about what PFAS is and how it spreads, there are regularly published news stories such as "Swedish crayfish can be stopped—too high levels of Pfas"[9], which made headlines in Sweden during the crayfish season in August 2022. Another interesting headline from March 2023 was "New research: 43 types of PFAS in common toilet paper"[10]. There is also a great focus and interest in research, both in conducting studies of PFAS effects and in the development and evaluation of various treatment techniques, not least within the waste industry. In addition to legal measures, voluntary measures and actions will be crucial to achieve sustainable development for future generations and to meet both national and EU environmental goals such as a toxic-free environment, responsible management of chemicals and waste, and good health and well-being.

Environmental Cooperation Sweden has reported that in Sweden there is currently only one full-scale waste management facility that treats PFAS in leachate, but that several new ones are in the works. At the Telge Recycling plant in Södertälje, Sweden, they use foam fractionation, and the degree of leachate purification is at least 90% for 6:2 FTS, PFDA, PFHpA, PFHxS, PFNA, PFOA, and PFOS. However, for PFBA, which is a short-chain substance that occurred in the highest concentrations but was also one of the most common in the project findings, the degree of purification was 0% (Miljösamverkan, 2022:28). This shows that different purification techniques are effective for different PFAS, and to achieve an acceptable result, a combination of several techniques may be required, and this needs to be further studied. This is crucial to subsequently be able to set conditions on treatment in the landfill's permit.

The last problem we intend to highlight is the fact that PFAS tend to travel long distances, both via air and water. PFAS is thus an international problem, and concerted efforts to deal with the problems that these substances cause are necessary. A study from 2022 shows that the levels of PFAS in rainwater often exceed both the US Environmental Protection Agency Lifetime Drinking Water Health Advisory, the Danish limit value for drinking water, and the EQS for EU surface water (Cousins et. al., 2022). Since leachate is mainly caused by rainwater infiltrating landfills, the fact that rainwater contains high concentrations of PFAS is a serious problem. This circles us back to the problem (1) of production and the importance of regulating the use of PFAS already at the production stage to try to reduce the load, and the risk it poses, with the concentrations that are now in the environment. Chemicals are needed in our society, but to achieve environmental goals, chemical policy must be reformed, and innovative chemistry must be encouraged.

6. CONCLUSIONS

The revision of the health-based guideline value from EFSA (EFSA, 2020) shows that PFAS are more dangerous than previously estimated and that it is crucial that the risk of long-term exposure to PFAS is minimized. Most of the Swedish assessment bases for limit and guideline values build on EFSA's tolerable daily intake for PFOS from 2008 (EFSA, 2008), and these need to be updated. Today, three PFAS in waste are regulated through the EU Regulation on Persistent Organic Pollutants (2019/1021), and to assess whether a waste has hazardous properties, Annex III to Directive 2008/98/EC on waste is applicable. The problems with PFAS are receiving more and more attention, not least in the waste industry, with the development and evaluation of effective purification techniques.

Since it takes time to implement updates within the legal system, a large responsibility is placed on the authorities that assess and issue permits for water operations or environmentally hazardous activities, including landfills. While it is possible to regulate purification and permitted levels of PFAS in leachate through conditions in permits for water operations and environmentally hazardous activities in accordance with the Swedish Environmental Code, this opportunity is rarely used. Here, a change needs to take place; acceptable levels of risk based on scientific knowledge need to be established, and the assessment of individual permits needs to be aligned with these requirements.

From a global perspective, international treaties and agreements provide a framework for countries to work together to address the environmental and health risks associated with PFAS. However, there is a need for more research on the global impact of PFAS contamination and the effectiveness of international agreements, such as the Stockholm Convention, in addressing these issues. It will require more collaboration and learning from each other as we move forward.

ACKNOWLEDGEMENTS

Financial support from Luleå University of Technology is greatly acknowledged. Furthermore, we are thankful to the anonymous reviewers at Detritus for their constructive comments.

REFERENCES

Agency for Toxic Substances and Disease Registry (ATSDR) (2021). Toxicological profile for perfluoroalkyls. U.S. Department of Health and Human Services. Centers for Disease Control and Prevention (U.S.). Agency for Toxic Substances and Disease Registry. https://doi.org/10.15620/cdc:59198.

Ahrens, L., Shoeib, M., Harner, T., Lee, S.C., Guo, R., Reiner, E.J. (2011). Wastewater Treatment Plant and Landfills as Sources of Polyfluoroalkyl Compounds to the Atmosphere. Environmental Science & Technology, 45 (19): 8098-8105. https://doi.org/10.1021/es1036173.

Allmyr, M. & Sternbeck, J. (2017). Manual för bedömning av lakvatten inom Revaq. Report, WSP Environmental, Assignment no: 10174991.

Bignert, A., Danielsson, S., Ek, C., Faxneld, S., Nyberg, E. (2017). Comments Concerning the National Swedish Contaminant Monitoring Programme in Marine Biota 2017 (2016 years data) - Övervakning av metaller och organiska miljögifter i marin biota 2017 (2016 års data). Report nr 10:2017. Swedish Museum of Natural History, Stockholm, Sweden.

Björklund, S., Weidemann, E., Jansson, S. (2023) Emission of Per- and Polyfluoroalkyl Substances from a Waste-to-Energy Plant–Occurrence in Ashes, Treated Process Water, and First Observation in Flue Gas. Environmental Science & Technology, 57, 27, 10089–10095. https://doi.org/10.1021/acs.est.2c08960.

Bolan, N., Hoang, S. A., Yan, Y., Ramanayaka, S., Koliyabandara, P., Chamanee, G., Wijesekara, H., Mukhopadhyay, R., Sarkar, B., Vithanage, M., Kirkham, M. B. (2021). Landfills as Sources of PFAS Contamination of Soil and Groundwater. I: Kempisty, D. M. & Racz, L. (ed.) Forever chemicals: Environmental, Economic, and Social Equity Concerns with PFAS in the Environment, 119–142. (First edition). Boca Raton: CRC Press.

Bonato, M., Corrà, F., Bellio, M., Guidolin, L., Tallandini, L., Irato, P., & Santovito, G. (2020). PFAS environmental pollution and antioxidant responses: an overview of the impact on human field. International journal of environmental research and public health, 17(21), 8020. https://doi.org/10.3390/ijerph17218020.

Commission Implementing Decision (EU) 2018/1147 of 10 August 2018 establishing best available techniques (BAT) conclusions for waste treatment, under Directive 2010/75/EU of the European Parliament and of the Council (notified under document C(2018) 5070) (Text with EEA relevance.) OJ L 208, 17.8.2018, p. 38–90.

Cossu, R., Grossule, V., & Lavagnolo, M. C. (2020). What about residues from circular economy and role of landfilling? Detritus, Volume 09 – March 2020, 1–3. https://doi.org/10.31025/2611-4135/2020.13920.

Council Directive 1999/31/EC on the landfill of waste. EGT L 182, 16.7.1999, p. 1–19.

Cousins, I. T., Johansson, J. H., Salter, M. E., Sha, B. & Scheringer, M. (2022). Outside the Safe Operating Space of a New Planetary Boundary for Per- and Polyfluoroalkyl Substances (PFAS). Environmental Science & Technology, 56(16), 11172–11179. https://doi.org/10.1021/acs.est.2c02765.

Danish Miljøministeriet (2021). Bekendtgørelse om vandkvalitet og tilsyn med vandforsyningsanlæg. BEK nr 2361 af 26/11/2021. https://www.retsinformation.dk/eli/lta/2021/2361 (accessed 2023-06-15).

Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy. EGT L 327, 22.12.2000, p. 1–73.

Directive 2006/118/EC of the European Parliament and of the Council of 12 December 2006 on the protection of groundwater against pollution and deterioration. EUT L 372, 27.12.2006, p. 19–31.

Directive 2006/122/EC of the European Parliament and of the Council of 12 December 2006 amending for the 30th time Council Directive 76/769/EEC on the approximation of the laws, regulations and administrative provisions of the Member States relating to restrictions on the marketing and use of certain dangerous substances and preparations (perfluorooctane sulfonates). OJ L 372, 27.12.2006, p. 32–34.

Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives. EUT L 312, 22.11.2008, p. 3–30.

Directive 2013/39/EU of the European Parliament and of the Council of 12 August 2013 amending Directives 2000/60/EC and 2008/105/EC as regards priority substances in the field of water policy. EUT L 226, 24.8.2013, p. 1–17.

Directive (EU) 2018/850 of the European Parliament and of the Council of 30 May 2018 amending Directive 1999/31/EC on the landfill of waste. EUT L 150, 14.6.2018, p. 100–108.

Directive (EU) 2020/2184 of the European Parliament and of the Council of 16 December 2020 on the quality of water intended for human consumption. EUT L 435, 23.12.2020, p. 1–62.

European Chemicals Agency (ECHA) (2022). ECHA/NR/22/05. Proposal to ban 'forever chemicals' in firefighting foams throughout the EU. Helsinki, 23 February 2022. https://echa.europa.eu/sv/-/proposal-to-ban-forever-chemicals-in-firefighting-foams-throughout-the-eu (accessed 2023-06-06).

European Chemicals Agency (ECHA) (2023). ECHA/NR/23/04. ECHA publishes PFAS restriction proposal. Helsinki, 7 February 2023. https://echa.europa.eu/sv/-/echa-publishes-pfas-restriction-proposal (accessed 2023-06-06).

European Commission, COM(2022) 540 final. Proposal for a directive of the European Parliament and of the Council amending Directive 2000/60/EC establishing a framework for Community action in the field of water policy, Directive 2006/118/EC on the protection of groundwater against pollution and deterioration and Directive 2008/105/EC on environmental quality standards in the field of water policy.

European Food Safety Authority (EFSA) (2008). Opinion of the Scientific Panel on Contaminants in the Food chain on Perfluorooctane sulfonate (PFOS), perfluorooctanoic acid (PFOA) and their salts. EFSA Journal 2008:653, 1–131. https://doi.org/10.2903/j.efsa.2008.653.

European Food Safety Authority (EFSA) (2020). Panel on Contaminants in the Food Chain on Risk to human health related to the presence of perfluoroalkyl substances in food. EFSA Journal 2020;18(9):6223, 391 pp. https://doi.org/10.2903/j.efsa.2020.6223.

Fenton, S. E., Ducatman, A., Boobis, A., DeWitt, J. C., Lau, C., Ng, C., Smith, J. S. & Roberts, S. M. (2021). Per-and polyfluoroalkyl substance toxicity and human health review: Current state of knowledge and strategies for informing future research. Environmental toxicology and chemistry, 40(3), 606–630. https://doi.org/10.1002/etc.4890.

Geological Survey of Sweden (SGU), Regulation SGU-FS 2013:2. Sveriges geologiska undersöknings föreskrifter om miljökvalitetsnormer och statusklassificering för grundvatten.

Geological Survey of Sweden (SGU), Regulation SGU-FS 2023:1. Sveriges geologiska undersöknings föreskrifter om kartläggning, riskbedömning och klassificering av status för grundvatten.

Giesy, J. P. & Kannan, K. (2001). Global distribution of perfluorooctane sulfonate in wildlife. Environmental Science & Technology, 35(7), 1339–1342. https://doi.org/10.1021/es001834k.

Grossule, V. & Stegmann, R. (2020). Problems in traditional landfilling and proposals for solutions based on sustainability. Detritus, Volume 12 - September 2020 (12), 78–91. https://doi.org/10.31025/2611-4135/2020.14000.

Hamid, H. & Li, L.Y. (2016). Role of wastewater treatment plant in environmental cycling of poly- and perfluoroalkyl substances. Ecocycles, 2(2):43-53. https://doi.org/10.19040/ecocycles.v2i2.62.

Hansen, K. J., Clemen, L. A., Ellefson, M. E. & Johnson, H. O. (2001). Compound-specific, quantitative characterization of organic fluorochemicals in biological matrices. Environmental Science & Technology, 35(4), 766–770. https://doi.org/10.1021/es001489z.

Kleineman, J. (2018). Rättsdogmatisk metod. I: Nääv, M. & Zamboni, M. (ed.) Juridisk metodlära, 21–46. (Second edition). Lund: Studentlitteratur.

Lohmann, R., Cousins, I. T., DeWitt, J. C., Glüge, J., Goldenman, G., Herzke, D., Lindstrom, A. B., Miller, M. F., Ng, C. A., Patton, S., Scheringer, M., Trier, X. & Wang, Z. (2020). Are fluoropolymers really of low concern for human and environmental health and separate from other PFAS? Environmental Science & Technology, 54(20), 12820–12828. https://dx.doi.org/10.1021/acs.est.0c03244.

Miljösamverkan Sverige (eng: Environmental Cooperation Sweden) (2022). PFAS vid deponier: Handläggarstöd med fokus på PFAS i lakvatten. Accessible in Swedish online: https://www.miljosamverkansverige.se/wp-content/uploads/2022-01-27-Rapport-PFAS-vid-deponier.pdf.

Minnesota Pollution Control Agency (MPCA) (2022). PFAS Air and Deposition Monitoring Report. Accessible: https://www.pca.state.mn.us/sites/default/files/tdr-g1-23.pdf.

Organization for Economic Co-operation and Development (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). Report ENV/JM/MONO(2018)7. Paris: OECD.

Pettersson, M. & Johansson, O. (2022). How cautious should we be? The role of the precautionary principle in the regulation of sewage sludge in Sweden. Detritus, Volume 21 - 2022, 105–113. https://doi.org/10.31025/2611-4135/2022.16227.
Pivato, A., Beggio, G., Maggi, S., Marrone, F., Bonato, T., Peres, F., Peng, W., & Lavagnolo, M. C. (2024). The presence of PFAS in wastes and related implications on the current and proposed European regulatory framework: a systematic critical review. Detritus, Volume 26 – March 2024, 89–105. https://doi.org/10.31025/2611-4135/2024.18352.
Racz, L. & Kempisty, D. M. (2021). PFAS Today and Tomorrow. I: Kempisty, D. M. & Racz, L. (ed.) Forever chemicals: Environmental, Economic, and Social Equity Concerns with PFAS in the Environment, 3–21. (First edition). Boca Raton: CRC Press.
Regulation (EU) 2019/1021 of the European parliament and of the council of 20 June 2019 on persistent organic pollutants. EUT L 169, 25.6.2019, s. 45–77.
Regulation (EU) 2022/2400 of the European parliament and of the council of 23 November 2022 amending Annexes IV and V to Regulation (EU) 2019/1021 on persistent organic pollutants. EUT L 317, 9.12.2022, s. 24–31.
Sandgren, C. (2009). Vad är rättsvetenskap?. Stockholm: Jure.
Swedish Agency for Marine and Water Management, Regulation HVMFS 2019:25. Havs- och vattenmyndighetens föreskrifter om klassificering och miljökvalitetsnormer avseende ytvatten.
Swedish Chemicals Agency (KEMI) (2015). Förekomst och användning av högfluorerade ämnen och alternativ. Stockholm: Kemikalieinspektionen rapport 6/15. Accessible in Swedish online: https://www.kemi.se/publikationer/rapporter/2015/rapport-6-15-forekomst-och-anvandning-av-hogfluorerade-amnen-och-alternativ.
Swedish Chemicals Agency (KEMI) (2021). Kunskapssammanställning om PFAS. Stockholm: Kemikalieinspektionen PM 1/21. Accessible in Swedish online: https://www.kemi.se/publikationer/pm/2021/pm-1-21-kunskapssammanstallning-om-pfas.
Swedish Chemicals Agency (KEMI) (2023a). Gränsvärden och riktvärden för PFAS – 9 oktober 2023. Accessible in Swedish online: https://www.kemi.se/download/18.db1a89d18b37a78175b303/1697636850410/Gransvarden-och-riktvarden-for-PFAS.pdf.
Swedish Chemicals Agency (KEMI) (2023b). PFAS. https://www.kemi.se/kemiska-amnen-och-material/pfas (accessed 2023-06-05).
Swedish Environmental Assessment Ordinance (SFS 2013:251).
Swedish Environmental Code (SEC) (SFS 1998:808).
Swedish Environmental Protection Agency (SEPA), Regulation NFS 2004:10. Naturvårdsverkets föreskrifter om deponering, kriterier och förfaranden för mottagning av avfall vid anläggningar för deponering av avfall.
Swedish Environmental Protection Agency (SEPA) (2008). Lakvatten från deponier. Report 8306, Mars 2008. Accessible in Swedish online: https://www.naturvardsverket.se/om-oss/publikationer/8300/lakvatten-fran-deponier/.
Swedish Environmental Protection Agency (SEPA), Regulation NFS 2020:6. Naturvårdsverkets föreskrifter om kommunala avfallsplaner om förebyggande och hantering av avfall.
Swedish Environmental Protection Agency (SEPA) (2022). Avfall i Sverige 2020. Report 7048, June 2022. Accessible in Swedish online: https://www.naturvardsverket.se/49d329/globalassets/media/publikationer-pdf/7000/978-91-620-7048-9.pdf.
Swedish Environmental Protection Agency (SEPA) (2023). Frågor och svar om PFAS och deponier. https://www.naturvardsverket.se/vagledning-och-stod/avfall/deponering-av-avfall/fragor-och-svar-om-pfas-och-deponier (accessed 2023-02-06).
Swedish Environmental Protection Agency (SEPA) (2024). Hantering av avfall enligt POP:s-förordningen. Vid hantering av POP:s-avfall. https://www.naturvardsverket.se/vagledning-och-stod/avfall/hantering-av-avfall-enligt-pops-forordningen/ (accessed 2024-03-04).
Swedish Food Agency (2021). Kartläggning av per- och polyfluorerade alkylsubstanser (PFAS) i Sveriges kommunala rå- och dricksvatten. Report L-2021 no. 21. Uppsala. Accessible in Swedish online: https://www.livsmedelsverket.se/globalassets/publikationsdatabas/rapporter/2021/l-2021-nr-21-kartlaggning-av-per-och-polyfluorerade-alkylsubstanser.pdf.
Swedish Food Agency, Regulation LIVSFS 2022:12. Livsmedelsverkets föreskrifter om dricksvatten.
Swedish Geotechnical Institute (SGI) (2011). Underlag för vägledning beträffande inventering, undersökning och riskklassning av gamla deponier. Lakvatten och deponigas. Diary number 2-0902-0098. Accessible in Swedish online: https://www.naturvardsverket.se/4a43bc/contentassets/a6d19b240af0402ba97ffb7651ee25fa/deponi-rapport-sgi-lakvatten-o-deponigas.pdf.
Swedish Geotechnical Institute (SGI) (2014). Inventering, undersökning och riskklassning av nedlagda deponier, Information och råd. Publication 14. Accessible in Swedish online: https://www.sgi.se/globalassets/publikationer/sgi-publikation/sgi-p14.pdf.
Swedish Geotechnical Institute (SGI) (2023). Nedlagda deponier. https://www.sgi.se/sv/vagledning-i-arbetet/deponi/nedlagda-deponier/ (accessed 2023-06-05).
Swedish Industrial Emissions Ordinance (SFS 2013:250).
Swedish Judgement of the Environmental Court of Appeal 2021-01-27 in case M 2164-19.
Swedish Judgement of the Supreme Court 2023-12-05 in case T 486-23.
Swedish Ordinance (SFS 2001:512) on landfilling.
Swedish Ordinance (SFS 2004:660) on management of the quality of the water environment.
Swedish Ordinance (SFS 2017:868) with county board instructions.
Swedish Waste Management (2022). 2021 Svensk Avfallshantering. Accessible in Swedish online: https://www.avfallsverige.se/media/wwbd2za0/svensk_avfallshantering_2021_web.pdf.
Swedish Waste Management (2023). Deponering av avfall. https://www.avfallsverige.se/fakta-statistik/avfallsbehandling/deponering-av-avfall/ (accessed 2023-06-05).
Swedish Waste Ordinance (SFS 2020:614).
Swedish Water Authorities (2016). Riktvärde för PFAS I grundvatten inför kartläggning 2016. Orientation decision 2016-11-16, no: 537-4640-16.
United Nations (UN) (2001). Stockholm Convention on Persistent Organic Pollutants.
United Nations Environment Programme (UNEP) (2009). Decision SC-4/17. Listing of perfluorooctane sulfonic acid, its salts and perfluorooctane sulfonyl fluoride. UNEP/POPS/COP.4-SC-4/17. Conference of the Parties to the Stockholm Convention on Persistent Organic Pollutants, Geneva, Switzerland. Accessible online: http://chm.pops.int/TheConvention/ConferenceoftheParties/ReportsandDecisions/tabid/208/Default.aspx.
United Nations Environment Programme (UNEP) (2019a). Decision SC-9/4. Perfluorooctane sulfonic acid, its salts and perfluorooctane sulfonyl fluoride. UNEP/POPS/COP.9-SC-9/4. Conference of the Parties to the Stockholm Convention on Persistent Organic Pollutants, Geneva, Switzerland. Accessible online: http://chm.pops.int/TheConvention/ConferenceoftheParties/ReportsandDecisions/tabid/208/Default.aspx.
United Nations Environment Programme (UNEP) (2019b). Decision: SC-9/12. Listing of perfluorooctanoic acid (PFOA), its salts and PFOA-related compounds. UNEP/POPS/COP.9-SC-9/12. Conference of the Parties to the Stockholm Convention on Persistent Organic Pollutants, Geneva, Switzerland. Accessible online: http://chm.pops.int/TheConvention/ConferenceoftheParties/ReportsandDecisions/tabid/208/Default.aspx.
United Nations Environment Programme (UNEP) (2020). Stockholm Convention on persistent organic pollutants (POPs). Text and Annexes revised in 2019. The Ninth meeting of the Conference of the Parties to the Stockholm Convention on Persistent Organic Pollutants, Geneva, Switzerland. Accessible online: http://chm.pops.int/theconvention/overview/textoftheconvention/tabid/2232/default.aspx.
United Nations Environment Programme (UNEP) (2021). Proposal to list long-chain perfluorocarboxylic acids, their salts and related compounds in Annexes A, B and/or C to the Stockholm Convention on Persistent Organic Pollutants. UNEP/POPS/POPRC.17/7. Conference of the Parties to the Stockholm Convention on Persistent Organic Pollutants, Geneva, Switzerland. Accessible online: http://chm.pops.int/Convention/POPsReviewCommittee/Chemicals/tabid/243/Default.aspx.
United Nations Environment Programme (UNEP) (2022). Decision SC-10/13. Listing of perfluorohexane sulfonic acid (PFHxS), its salts and PFHxS-related compounds. UNEP-POPS-COP.10-SC10/13. Conference of the Parties to the Stockholm Convention on Persistent Organic Pollutants, Geneva, Switzerland. Accessible online: http://chm.pops.int/TheConvention/ConferenceoftheParties/ReportsandDecisions/tabid/208/Default.aspx.
United States Environmental Protection Agency (EPA) (2021). PFAS Master List of PFAS Substances. https://comptox.epa.gov/dashboard/chemical-lists/pfasmaster (accessed 2023-06-12).

[1] All environmentally hazardous activities that require a permit in accordance with Ch. 9 of the Swedish Environmental Code must submit an environmental report every year to the Swedish County Administrative Board. Environmental reporting aims to monitor and follow up on businesses adherence to the conditions specified in their applicable permit, as well as enable them to enhance their environmental work (Swedish Environmental Code, Ch. 26 Para. 20).

[2] Swedish database with a manager's guide on contaminated areas. Everything from modern landfills in operation to smaller, closed landfills is registered. EBH-portal is operated by the Swedish County Administrative Boards. https://www.ebhportalen.se/.

[3] As an example, in 2013, among the world's highest levels of PFAS were measured in people in Kallinge, Sweden. The highest level was 1800 ng/ml, the lowest level was 91 ng/ml, and the average level was about 600 ng/ml. A "normal" person can have about 10 ng/ml of PFAS in the body (Case T 486-23).

[4] A collaboration between county administrative boards, the Swedish Environmental Protection Agency, the Swedish Board of Agriculture, and the Swedish Agency for Marine and Water Management. The goal of the coalition is to increase consensus between the different county administrative boards and thereby create a more uniform exercise of authority through supervisory guidance, supervision, and assessments in the area of Swedish environmental law.

[5] SEPA's regulation is designed in accordance with the Landfill Directive (Council Directive 1999/31/EC of 26 April 1999 on the Landfill of Waste) and the Council Decision of 19 December 2002 on procedures for the reception of waste at landfills in accordance with Article 16 and Annex II to Directive 1999/31/EC. The directive is a minimum directive, and the established acceptance criteria are not exhaustive.

[6] Revaq is a certification system that aims to improve the quality of plant nutrients from sludge by reducing the flow of hazardous substances to sewage treatment plants.

[7] In Revaq's manual, the reporting limit for PFOS to be investigated and evaluated in leachate is set at 5 ng/L. The assessment system is based on how leachate affects the sludge quality and its risk of negative effects on health and the environment. In sludge, PFOS is set at a low risk level of 0.12 mg/kg dry substance (Allmyr and Sternbeck, 2017:8 and 12).

[8] Sweden is divided into five different water districts, based on the borders of the major sea basins and catchment areas, and in each district, the government has appointed one of the County Administrative Boards to act as water district authority. https://www.vattenmyndigheterna.se/om-vattenmyndigheterna.html (accessed 2023-06-02).

[9] Swe: Svenska kräftor kan stoppas – för höga halter Pfas. Title on Swedish TV4 on September 22, 2022. https://www.tv4.se/artikel/67sfKlvFP6UyY6rOUqMxSj/svenska-kraeftor-stoppas-foer-hoega-halter-miljoegift (accessed 2023-06-22).

[10] Swe: Ny forskning: 43 sorter PFAS i vanligt toalettpapper. Title in Today's PS Life Science (Swe: Dagens PS Life Science) on March 17, 2023. https://www.dagensps.se/life-science/ny-forskning-43-sorter-pfas-i-vanligt-toalettpapper/ (accessed 2023-06-22).