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Screening of fluorinated substances used in lithium-ion batteries

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Screening of fluorinated substances used in lithium-ion batteries

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Summary
Lithium-ion batteries (LIBs) are key to modern energy storage due to their high energy density and rechargeability. LIB components contain fluorinated compounds, including ionic liquid anions such as hexafluorophosphate (PF_6^-), tetrafluoroborate (BF_4^-) and bis(trifluoromethanesulfonyl)imide (TFSI) in electrolytes. However, limited data exist on emissions and environmental behaviour of these substances across the LIB lifecycle. This screening study aimed to detect fluorinated substances linked to LIBs in water near three Swedish sites: a recycling facility (Stena Metall AB, Halmstad), an R&D center (Northvolt Labs, Västerås), and a landfill (Sofielund, Stockholm), as well as in wastewater treatment effluent from four cities and drinking water from two cities.

The two inorganic fluorinated compounds, PF_6^- and BF_4^-, were measured at levels up to 39 000 ng/L and 2 400 ng/L, respectively, near the industrial site in Halmstad. Of the three bis-perfluoroalkyl sulfonimide (bisFASI) homologues analysed, TFSI was the most prevalent. Around the recycling facility, TFSI was measured at 33-82 ng/L, and at even higher concentrations downstream of the site in a nature reserve (106 ng/L). TFSI was present in the wastewater treatment plant effluents from all four cities, at concentrations ranging from 0.4 to 2.1 ng/L. Trifluoroacetic acid (TFA) was the dominant fluorinated substance across most samples, whereas other short-chain PFAS and inorganic ions, including BF_4^-, TFMS, PFPrS, PFBS, PFHxS (linear [L] and branched [br]), and TFSI, exhibited site-specific occurrence.

These results demonstrate that LIB-associated fluorinated substances are present in the environment and at elevated concentrations around recycling and waste management sites. This screening study highlights the need for expanded monitoring and improved treatment strategies to minimize the emissions of these hazardous chemicals into the environment.

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Sammanfattning på svenska

Litiumjonbatteriet är en central teknik som möjliggör modern energilagring tack vare dess höga energitäthet och återuppladdningsbarhet. För att uppnå dessa egenskaper används fluorerade ämnen i komponenter hos litiumjonbatterier, inklusive joniska vätskeanjoner såsom hexafluorofosfat (PF_6^-), tetrafluorborat (BF_4^-) och bis(trifluormetansulfonyl)imid (TFSI) i elektrolyter. Det finns dock begränsad kunskap om utsläpp och miljöbeteende hos dessa persistenta ämnen under hela livscykeln för litiumjonbatterier. Syftet med denna screeningsstudie var att undersöka förekomsten av per- och polyfluorerade alkylsubstanser (PFAS) och andra litiumjonbatterirelaterade fluorerade föreningar i svenska ytvatten, avloppsvatten och dricksvatten i närheten av en batteriåtervinningsanläggning (Stena Metall AB, Halmstad), en forsknings- och utvecklingsanläggning (Northvolt Labs, Västerås) samt en deponi (Sofielund, Stockholm).

Förhöjda halter av PF_6^- (upp till 39 000 ng/L) och BF_4^- (upp till 2 400 ng/L) påträffades nära Kistinge industriområdet i Halmstad. Av de tre analyserade bis-perfluoralkylsulfonimid (bisFASI)-homologerna detekterades TFSI i majoriteten av proverna, vilket bekräftar dess utbredda förekomst. Runt återvinningsanläggningen uppmättes TFSI till 33–82 ng/L. Ännu högre halter detekterades nedströms i ett naturreservat (106 ng/L). Trifluorättiksyra (TFA) dominerade i de flesta prover, medan andra kortkedjiga PFAS och oorganiska joner (BF_4^-, TFMS, PFPrS, PFBS, PFHxS [L+br], TFSI) var platsspecifika.

Resultaten visar att litiumjonbatterirelaterade fluorerade ämnen förekommer i miljön och i förhöjda halter kring återvinnings- och avfallshanteringsanläggningar. Studien understryker behovet av utökad övervakning och förbättrade reningsstrategier för att minimera risken av utsläpp av farliga kemikalier till miljön.

Introduction

Lithium-ion batteries (LIBs) are widely used for energy storage in many technologies, from portable devices such as laptops and mobile phones to electric vehicles. LIBs are rechargeable and offer superior electrical performance with high energy and power density relative to their weight compared to other battery technologies such as sodium-ion and lead-acid batteries (Pinegar & Smith, 2019). Fluorinated substances are used in LIB components, particularly in electrolytes, due to their strong chemical bond, high electronegativity, nonflammability, and cost effectiveness (Wang et al., 2024). For example, ionic liquid anions such as hexafluorophosphate (PF_6^-), tetrafluoroborate (BF_4^-), trifluoromethane sulfonic acid (TFMS) and bis-perfluoroalkyl sulfonimides (bisFASIs) are used as electrolytes to improve electrical conductivity (Guelfo et al., 2024; Neuwald et al., 2021) (see Figure 1 for molecular structures). Also, polyvinylidene fluoride (PVDF) and other fluoropolymers can be used in LIBs as an electrode binder and separator (Rensmo et al., 2023; Savvidou et al., 2024; Wang et al., 2024).

The environmental impacts of many of the fluorinated substances used in LIBs are not well studied and there is a lack of data regarding emissions over the full LIB lifecycle (production, use and end-of-life). Battery production is one example of the industrial applications of ionic liquids such as $LiBF_4$ and $LiPF_6$, which were first reported in German rivers in 2021 (Neuwald et al., 2021). Since then, studies have reported the presence of these inorganic fluorinated substances in effluent from wastewater treatment plants (WWTPs) (Neuwald et al., 2023; Tisler et al., 2025), a waste management facility (Pettersson et al., 2024), and drinking water (He et al., 2024; Jiao et al., 2023). These small and persistent anions are extremely mobile, making them difficult to remove during wastewater treatment (Neuwald et al., 2023) and facilitating their uptake via plant roots (Seelig et al., 2025). BisFASIs were detected in the environment for the first time in 2021 (Neuwald et al., 2021). They were also observed in proximity to 3M manufacturing facilities in Minnesota and Antwerp (Guelfo et al., 2024). Bis(trifluoromethanesulfonyl)imide (TFSI) was detected in drinking water from China (Jiao et al., 2023), and in a waste management facility (Pettersson, Jogsten, et al., 2024). Considering the expected growth in the production, use, and recycling of LIBs over the coming decades, driven by the transition from fossil fuels to renewable energy and electric transportation, associated emissions are likely to increase.

Aim

This screening study investigates the occurrence of per- and polyfluoroalkyl substances (PFAS) and other fluorinated compounds associated with lithium-ion batteries (LIBs) in the Swedish environment. Surface water samples were collected near potential point sources, including a battery recycling facility in Halmstad, a battery research and development site in Västerås, and a general waste landfill near Stockholm that also temporarily stores electronic waste. To assess broader environmental exposure, the study also included drinking water from two locations, as well as effluent from wastewater treatment plants (WWTPs) from the three locations. Additionally, WWTP effluent from Skellefteå was sampled due to its proximity to Northvolt's gigafactory.

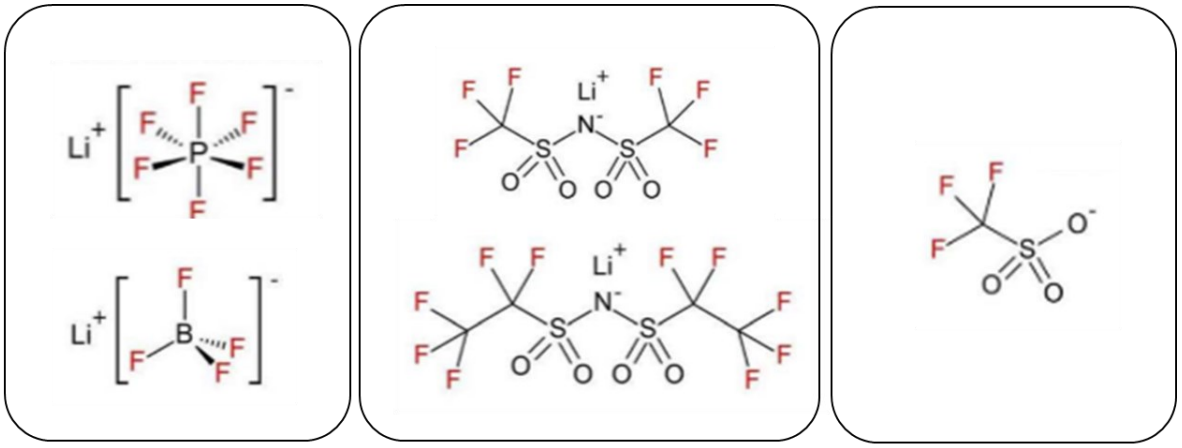

Figure 1. Molecular structures of selected fluorinated ionic liquids known to be used in lithium-ion batteries (LIBs).

Methods

Chemicals and reagents

A total of 21 PFAS were monitored in this study, including 9 perfluoroalkyl carboxylic acids (PFCAs), 9 perfluoroalkane sulfonic acids (PFSAs), and 3 bisFASIs. Additionally, 2 inorganic fluorinated compounds (BF_4^- and PF_6^-) were analysed. $^{13}C_2$-TFA was purchased from Cambridge Isotope Laboratories, Inc, H-TFSI from Sigma Aldrich, LiBETI and LiNFSI from TCI Chemicals, and inorganic fluorinated compounds ($NaBF_4$ and $NaPF_6$) were purchased from Merck KGaA (Darmstadt, Germany). Other native and isotope-labelled PFAS were purchased from Wellington Laboratories (Guelph, Canada) (Table S1). LC-MS grade methanol was purchased from Merck KGaA (Darmstadt, Germany). The LC-MS grade ammonium acetate and acetic acid were purchased from Sigma- Aldrich (United States). All water used for experiments was purified using a Milli-Q system.

Sampling

Samples were collected between February and April 2025. An overview of all collected samples including sample type, date and coordinates is provided in Table S2. All surface water samples were obtained from publicly accessible sampling sites. Effluent samples were collected by personnel at each respective WWTP. Landfill leachate samples were acquired with the assistance of a facility employee, who also provided access to the site.

Before sampling, 1 litre polypropylene (PP) bottles were prerinsed with methanol followed by MilliQ water. At the sampling points the bottles were rinsed three times with sample water before the bottles were filled. Water samples were stored in a freezer/fridge prior to extraction.

Sample extraction

The water samples (except drinking water) were filtered using a paper filter (Munktell Ahlstrom Grade 3) and adjusted to pH ~4 using acetic acid. Prior to extraction, samples were spiked with 1 ng of mixed PFAS internal standard solution and 100 ng of TFA internal standard ($^{13}C_2$-TFA). Samples (1 L [Batch 1] and 250 mL [Batch 2-6]) were extracted with Oasis WAX SPE cartridges (Waters; 6 cm^3, 150 mg sorbent, 30 µm particle size) conditioned with 4 mL 0.3% ammonium hydroxide in methanol, followed by 4 mL of 0.1 M acetic acid. Thereafter, the sample was loaded (0.25 L or 1 L). The

cartridges were subsequently washed with 5 mL of 20% methanol in 0.1 M acetic acid. After drying the cartridges for 20 minutes, extracts were eluted using 4 mL 0.3% ammonium hydroxide in methanol into a PP tube. Subsequently, the extracts were cleaned up using a Supelclean™ ENVI-Carb™ SPE (bed wt. 1 g 12 mL), which was conditioned with 2 mL methanol. The PP tubes were rinsed with 4 mL methanol, which was then added to the ENVI-Carb SPE cartridge. The extracts were concentrated to incipit dryness and reconstituted in 250 µL methanol before transferring to an Eppendorf filter (VWR Centrifugal Filter, modified nylon 0.2 µM, 500 µL). After vortexing, the extracts were transferred to a vial using a glass pipette and fortified with 50 µL recovery standard (1 ng $^{13}C_8$PFOA and $^{13}C_8$PFOS) and 300 µL water buffer (4 mM ammonium acetate). A schematic overview is presented in Figure S1.

Instrumental analysis

Target analyses were performed on a Thermo ultrahigh performance liquid chromatograph coupled to a Thermo TSQ Quantiva triple quadrupole mass spectrometer (UHPLC-MS/MS) and were based on a previous study by He et al. (2024). A list of targets is presented in Table S1. Inorganic fluorinated substances (BF_4^-, PF_6^-) and (ultra)short-chain PFAS (TFA, PFPrA, PFBA, TFMS, PFEtS, PFPrS, and PFBS) were chromatographed on a Trinity P1 anion exchange column coupled with a guard column (2.1 × 100 mm, 3 µm and 2.1 × 10 mm, 3 µm, respectively). PFCAs (PFPeA, PFHxA, PFHpA, PFOA, PFNA, and PFDA), PFSAs (PFPeS, PFHxS, PFHpS, PFOS, PFNS, and PFDS), and bisFASIs (bis(trifluoromethanesulfonyl)imide [TFSI], bis(pentafluoroethanesulfonyl)imide [BETI], and bis(nonafluorobutanesulfonyl)imide [NFSI]) were chromatographed using an Atlantis Premier BEH C18 AX column (2.1 × 100 mm, 1.7 µm; Waters). In addition, an extra C18 isolator column (2.1 × 50 mm; Waters) was mounted before the injector to trap possible PFAS contamination. Mobile phase gradient programs are presented in Table S3.

Data handling

Data processing was carried out using TraceFinder 4.1 software. All targets were quantified by isotope dilution, using weighted (1/x) linear calibration curves. Limits of quantification (LOQs) were determined by the lowest calibration concentration that showed a well-shaped peak with intensity >1e3 and S/N >3 (Table S4), based on a sample volume of 250 mL. Compounds that did not have an exactly matching IS were semi-quantified using a similar structured IS; this was the case for BF_4^-, PF_6^-, PFPrA, TFMS, PFPrS, PFPeS, PFHpS, PFNS, TFSI, BETI, and NFSI (selected ISs are specified in Table S1) For compounds that were not present in the calibration standard, but that were detected in the samples (branched isomers, PFNS), a similar structure was used for quantification.

QA/QC

Field blanks were included to assess possible contamination during sampling. The field blanks were acquired by filling precleaned PP bottles with one litre MilliQ water and opening them shortly at the sampling site after which they were treated like real samples. Each batch also included a procedural blank (solvents only) to assess contamination during sample preparation. Repeatability of the extraction and instrumental analysis was assessed by including triplicates for four samples. Solvent blanks were injected every 8-10 runs to assess carry-over and instrumental contamination. PFOS contamination was observed in one of the extraction batches and affected a few samples for which a blank subtraction was performed and the affected samples are marked as “contaminated” in Table S4. The Halmstad field blank did not contain any of the target analytes, while the Västerås field blank showed low concentrations of PFHxS, L-PFHpS, and br-PFHpS (3.9, 2.6 and 3.5 ng/L, respectively). No blank subtraction was performed.

Accuracy and precision were assessed using spike/recovery experiments consisting of surface water samples from Spegeldammen (a pond nearby Stockholm University) analysed in the same manner as above, both with (*n*=3) and without (*n*=3) a fortification of 50 ng PFAS-mix, 4000 ng TFA, 10 ng bisFASI-mix, as well as 300 ng BF_4^- and PF_6^-. Average percent recoveries were within 80-120% for most substances (Figure 2). High recoveries were observed for the inorganic compounds BF_4^- (139%) and PF_6^- (174%), possibly due to the use of a non-matching IS ($^{13}C_2$-TFA). Percent relative standard deviation (RSD) was also reasonable for most targets (1.5-28%) with the exception of PF_6^- (35%) and PFPrA (42%), which displayed slightly larger variances.

Recoveries of the isotopically-labelled internal standards were also assessed, by comparing ratios between the areas of the IS and RS in the extracts to the ratios found in the calibration solution. On the Atlantis column, average IS recoveries ranged from 66-77% for MPFCAs ($C_{6\text{-}10}$) and MPFSAs ($C_{4,6,8}$). Recoveries for MPFBA and MPFPeA were however much higher in the blanks (67-87%) compared to the water samples (average 32%), probably due to matrix effects.

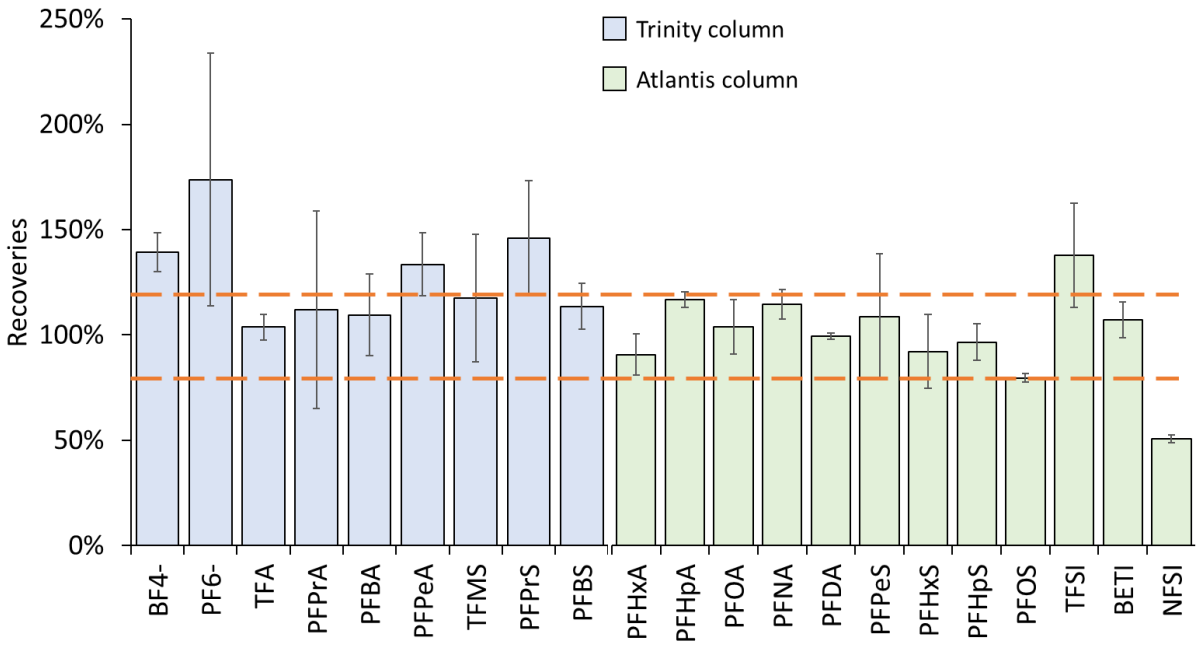

Figure 2. Percent recoveries for spiked surface water samples (*n*=3) minus the background levels. The dashed lines indicate the 80% and 120% recoveries.

Results and Discussion

Battery recycling site area (Halmstad)

Stena Metall AB owns multiple buildings in the Kistinge industrial area (Halmstad), including the Stena Nordic Recycling Centre (SNRC) and Stena Battery Recycling Centre (BRC) (Figure 3). The SNRC carries out various recycling and waste management processes, including sorting, processing and treatment of various materials such as metals, plastics, cables, electronic products and batteries (Stena Recycling Kontrollprogram, 2024). This also includes handling and storage of LIBs from hybrid and electric cars. According to their website, Stena Recycling has Europe's most advanced battery recycling facility, with the capacity to handle 10 000 tonnes of battery material per year, equivalent to around 30 000 electric car batteries (Stena Recycling, 2025). Stena BRC is in the start-up phase and processes LIBs from vehicles mechanically, along with sorting of the different components, i.e., electrolytes, plastics, metals and black mass. The black mass is sent to partners for hydrometallurgical separation (Stena Battery Centre Miljörapport, 2023).

Sampling points

Stormwater from the operational areas from SNRC is diverted to equalization and sedimentation ponds (Dam 1 and 4), which are discharged into the recipient stream: the Kistingebäcken stream at sampling point HA-4 (Figure 3 and 4) (Stena Recycling Kontrollprogram, 2024). HA-5 and HA-6 were collected upstream of the discharge point. Another sample was collected further downstream where Kistingebäcken connects to Trönningeån (HA-7) which flows through a nature reserve and bird protection area. Trönningeån eventually has its outlet into the sea at Laholmsbukten. Two samples were collected further upstream from Trönningeån (HA-8 and HA-9). Additionally, samples were collected from two stormwater ponds located near the Stena BRC (HA-10 and HA-11). For reference, a water sample was collected from a lake outside of the urban and industrial area (HA-13). Another sample was collected north of the Kistinge industrial area (HA-3). A WWTP effluent sample was kindly provided by Västra Standen (HA-2) and a sample was collected from the WWTP outfall area (HA-1). Also, a drinking water sample was included (HA-12).

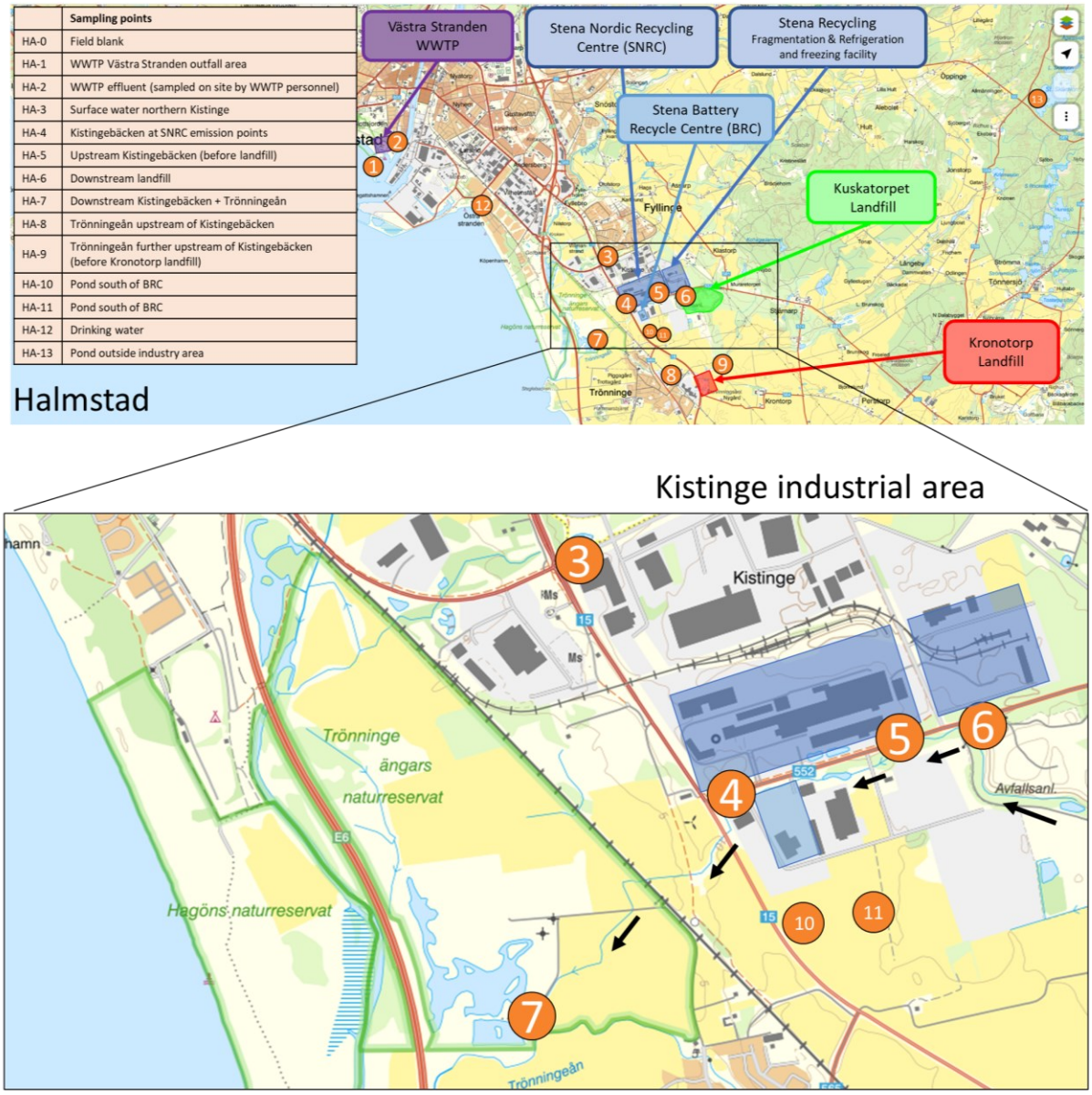

Figure 3. Sampling points for water samples in Halmstad; detailed information including coordinates are listed in Table S2. Arrows indicate the direction of the Kistingebäcken water stream. Map source: Lantmäteriet.

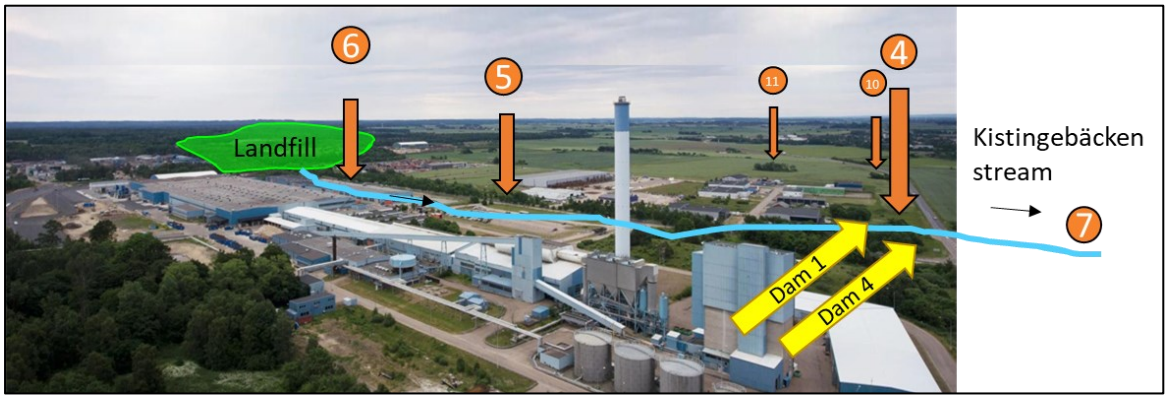

Figure 4. Areal picture of Stena Recycling facility in Kistinge industrial area with sampling points in orange and the Kistingebäcken stream marked in light blue. Yellow arrows indicate the emissions from two dams from Stena Metall AB into Kistingebäcken at sampling point 4. Photo source: AFRY.

Inorganic fluorinated compounds

Inorganic fluorinated substances BF_4^- and PF_6^- were detected in the majority of the samples from Halmstad (Figure 5; Table S4). The highest levels were detected around the industrial site with concentrations up to almost 40 000 ng/L for PF_6^-, and nearly 2 500 ng/L for BF_4^-. Caution should be observed for these results since PF_6^- levels were above the calibration range for samples with the highest levels (HA-4, -5, -6, and -7). Also, double peaks were observed at the highest concentrations, which might be a result of column overloading (Figure S2). A previous study has reported concentrations of BF_4^- and PF_6^- up to 10 000 ng/L in surface water from Germany (Neuwald et al., 2021). Another study reported levels of circa 4 500 and 2 000 ng/L for BF_4^- and PF_6^- in water from withing a waste management facility in Sweden (Pettersson et al., 2024). Both BF_4^- and PF_6^- were below detection limits in Halmstad drinking water, although they have been reported previously in drinking water from Stockholm (7.6 ng/L [BF_4^-] and 0.7 ng/L [PF_6^-]) and Shanghai (9.3-195 ng/L [BF_4^-] and 93-391 ng/L [PF_6^-]) (He et al., 2024; Jiao et al., 2023).

PFCAs

PFCA levels were highest in Kistingebäcken around the Stena Recycling site (HA-4, HA-5, HA-6) with concentrations up to almost 4 000 ng/L for TFA. For comparison, average TFA levels reported in European surface waters were 1 220 ng/L (PAN Europe, 2024). PFOA levels were highest in point HA-6, directly after the landfill at 250 ng/L and decreased to 81 and 82 ng/L further downstream in HA-5 and HA-4, respectively. HA-13 was sampled to be a reference point outside of the urban and industrial areas. However, PFPrA levels measured were much higher in HA-13 than in the rest of the samples; 1 240 ng/L compared to the next-highest samples HA-5 at 216 ng/L. Also, PF_6^- was higher in HA-13 (431 ng/L) compared to the other water samples not related to Kistingebäcken (<80 ng/L).

PFSAs

Among PFSAs, PFBS was consistently observed at the highest concentrations. PFBS levels at HA-4 (SNRC's emission point) was 1 280 ng/L. Further upstream PFBS concentration were 959 ng/L and 392 ng/L in HA-5 and HA-6, respectively. Further downstream of the emission point, in a nature reserve (HA-7), PFBS levels were measured at 292 ng/L. Stena's own environmental report measured ΣPFAS11 in two of their dams that are being released into Kistingebäcken at 6 800 ng/L (ca 90% PFBS) for Dam 1 and 656 ng/L for Dam 4 (ca 50% PFBS) (Stena Recycling Miljörapport, 2023). The ultrashort chain TFMS was measured at the highest concentrations at SNRC's emission point (HA-4) at 489 ng/L confirming emissions into Kistingebäcken. Further downstream of Kistingebäcken at HA-7, TFMS was measured at 223 ng/L (Figure 5).

BisFASIs

Among the bisFASIs, TFSI was the most abundant target. This substance was detected upstream of SNRC's emission point at 33 and 75 ng/L (HA-5 and HA-6, respectively). It was measured at 82 ng/L at the emission point (HA-4), and even higher concentrations at point HA-7 which is located further downstream of Kistingebäcken outside the industrial area in a nature reserve and bird protection area. BETI was also detected at points HA-4 to HA-7, but at lower concentrations (<0.6 ng/L). TFSI was also detected at points HA-10 and HA-11, two ponds near Stena BRC, at concentrations 3 and 1 ng/L, respectively. It was also detected in the WWTP effluent from Halmstad at 2 ng/L.

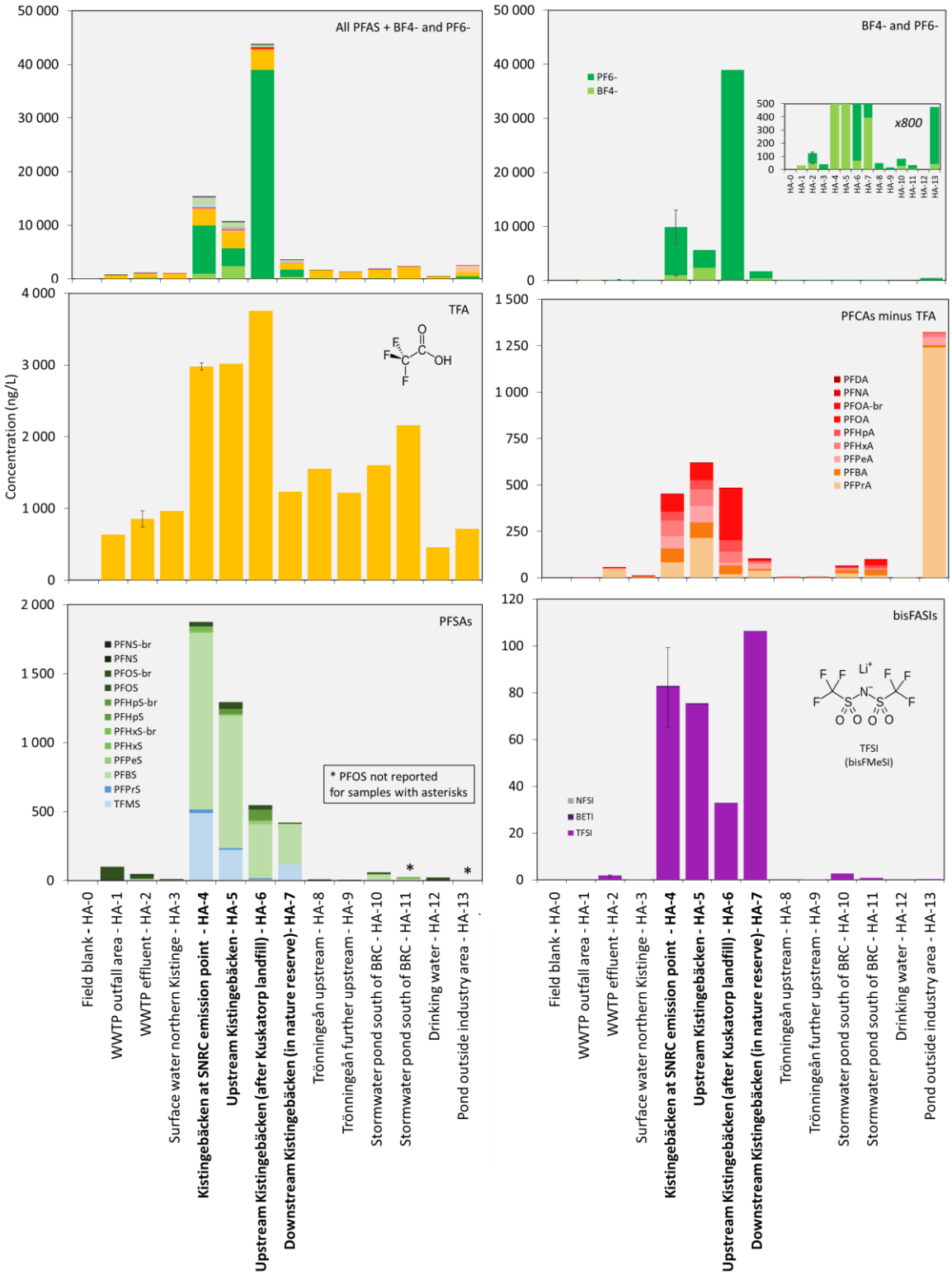

Figure 5. Concentrations (ng/L) for target analytes in water samples collected in Halmstad. Samples collected in the Kistingebäcken stream, upstream and downstream of the SNRC emission point (HA-4) are presented in bold. Error bars indicate standard deviation for *n*=3. Asterisks in PFSAs graph indicate samples where PFOS (L+br) could not be measured due to contamination. Exact concentrations are presented in Table S4.

Battery research and development area (Västerås)

Nine samples were collected in the Västerås area (Figure 6), of which four samples were taken from trenches/streams around the Northvolt Labs site (VÄ-1, -2, -3, -4). Samples were collected on the 17th of February 2025, which was before Northvolt announced its bankruptcy on the 12th of March 2025. In general, the processes at Northvolt Labs take place in closed systems with a high degree of recycling and the process water that cannot be recirculated within the facility is released into the municipal wastewater network (Northvolt Samrådsunderlag, 2024). Stormwater from the Finnslätten industrial area is led via pipes that flow into the Svartån river at Hovdestalund (Northvolt Samrådsunderlag, 2024), and a sample was collected directly from a discharge pipe (VÄ-5). Two more samples were collected further downstream of the Svartån river (VÄ-6 and VÄ-7), with the final recipient being Lake Mälaren. Additionally, a WWTP effluent sample (VÄ-8) was kindly provided by Kungsängens WWTP and a drinking water sample (VÄ-9) was included.

Overall, PFAS levels were much lower in the water samples from Västerås compared to the samples from Halmstad, which is not surprising as it is an R&D site and a much smaller scale compared to Halmstad. Also, there are no known emissions directly into the water streams around the Northvolt Labs site, and no known historical emissions (as is the case in Halmstad with a landfill nearby and other industries that are possible contributors).

For the inorganic fluorinated substances, an elevated concentration of PF_6^- was observed at point VÄ-2 east of Northvolt Labs (386 ng/L), as well as higher PFCA levels (61, 32, 19 ng/L for PFBA, PFHxA and PFOA, respectively). A higher concentration of TFA (2365 ng/L) was also observed at VÄ-4, south of Northvolt Labs, compared to the other samples (Figure 7; Table S4). None of the bisFASIs were detected in the samples around NV Labs area. However, TFSI was detected at low concentrations in the Svartån river (VÄ-6), drinking water, and WWTP effluent from Västerås at 0.1, 0.8, and 0.1 ng/L, respectively.

	Sampling points
VÄ-0	Field blank
VÄ-1	Trench northwest of NV Labs
VÄ-2	Stream east of NV Labs
VÄ-3	Stream southeast of NV Labs (in the forest)
VÄ-4	Trench south of NV Labs
VÄ-5	Discharge point into Svartån river (at Hovdestalund) from municipal stormwater (including from Finslätten industrial area)
VÄ-6	Svartån river downstream (Blåsbo)
VÄ-7	Svartån river downstream before release to Lake Mälaren
VÄ-8	WWTP effluent
VÄ-9	Drinking water (Rönnby)

Figure 6. Sampling points for water samples in Västerås. Map source: Lantmäteriet.

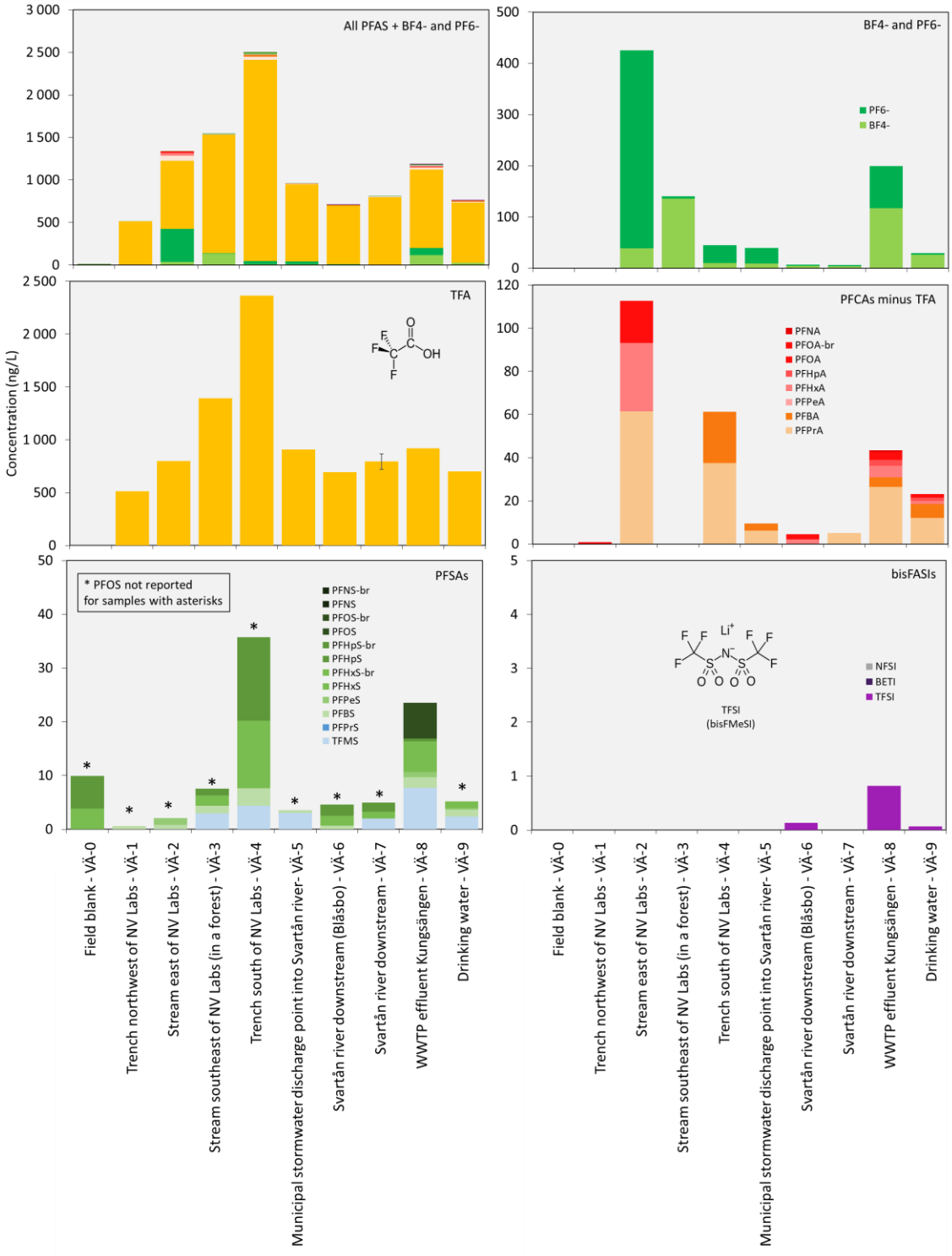

Figure 7. Concentrations (ng/L) in water samples collected in Västerås. Exact concentrations are presented in Table S4. Asterisks in PFSAs graph indicate samples where PFOS (L+br) could not be reported due to contamination.

Landfill area (Sofielund, Huddinge)

Sofielund landfill is located in the Gladö industrial area in Huddinge and operated by SRV Recycling. It is one of the largest waste facilities in Sweden with a wide range of operations, including sorting, temporary storage and treatment of household and industrial waste, as well as storing and handling hazardous waste, and three landfill areas (SRV årsrapport, 2023). Sofielund does not specifically collect LIBs but receives electronic waste which may can contain LIBs. The landfill site has their own leachate treatment facility and after treatment, the water is led to the Henriksdal WWTP in Stockholm.

Two samples were included in this study, a landfill leachate sample from the active landfill (LF-1 ["D3FM1" in Sofielund's SRV 2023 annual report]) and a surface water sample from a stream in the forest downstream the landfill, after the equalization basin near the hazardous waste handling area (LF-2 ["Y4" in Sofielund's SRV 2023 annual report]), which flows further into lake Orlången (Figure 8). The sample LF-2 is not only affected by the Sofielund facility, but also other operators in the Gladö industrial area. For example, a car dismantling facility and a shredding facility could potentially also affect the sampling site.

Ultrashort chain PFAS were the main contributors with TFA levels of 19 800 ng/L and PFPrA at 18 300 ng/L, followed by the short chain PFAS PFBA (2 500 ng/L) and PFBS (2 100 ng/L) (Figure 9; Table S4). Interestingly, the inorganic fluorinated compounds were detected at higher concentrations in the stream in the forest close to the hazardous waste handling downstream of the site (LF-2; which is also affected by other operators) than in the landfill leachate (LF-1). For PFSAs, the landfill leachate had highest concentrations for the short- and ultrashort chain PFAS PFBS and TFMS at 2 100 and 776 ng/l, respectively. In LF-2, TFMS was the highest measured PFSA at 211 ng/L.

For comparison, the landfill's annual report from 2023 observed PFAS-11 concentrations of 16 000 ng/L in the landfill leachate (LF-1) and 1 400 ng/L in the stream nearby hazardous waste handling (LF-2) (SRV årsrapport, 2023), which were measured here at ~10 000 ng/L (excluding PFOS due to a contamination problem during extraction) and ~450 ng/L, for LF-1 and LF-2 respectively. TFSI was detected in both samples at 329 ng/L and 26 ng/L in LF-1 and LF-2, respectively. BETI was detected only in LF-1 at a concentration of 4 ng/L.

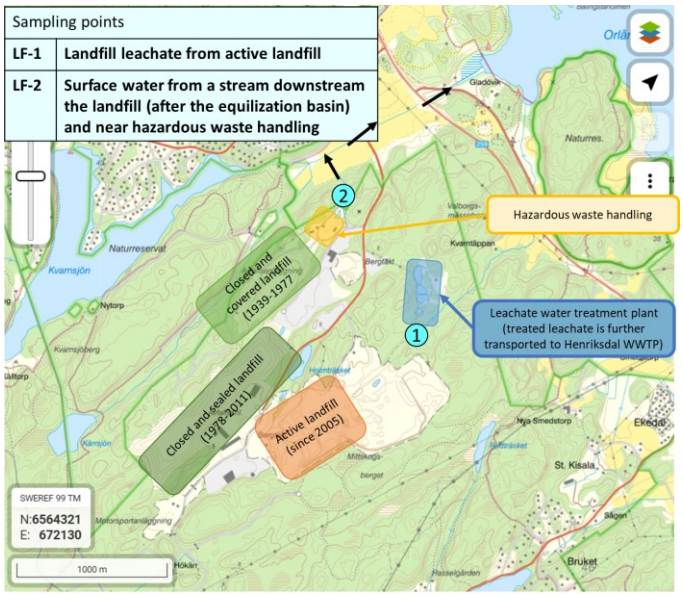

Figure 8. Sampling points for samples collected from Sofielund's landfill in Huddinge. Map source: Lantmäteriet.

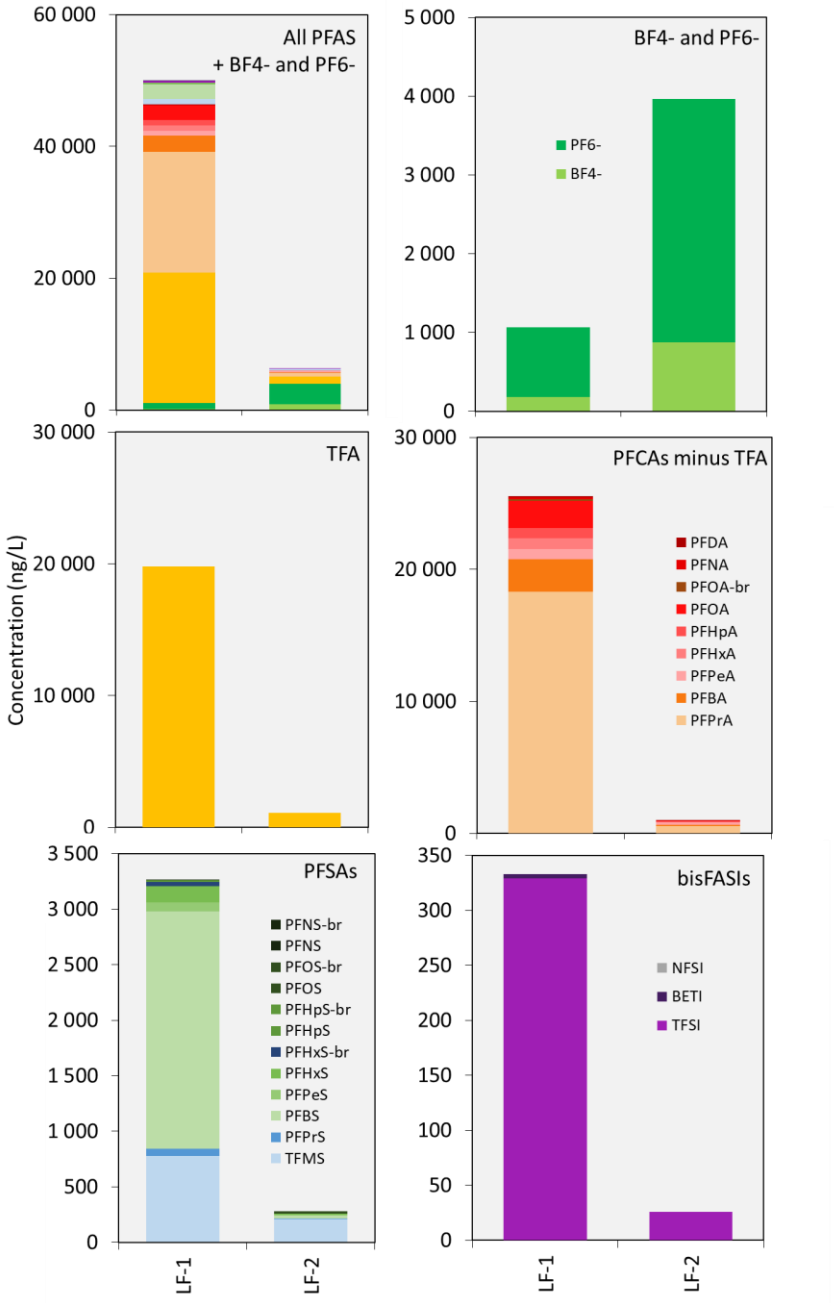

Figure 9. Concentrations (ng/L) in landfill leachate from an active landfill (LF-1) and from a stream downstream Gladö industrial area (LF-2). Exact concentrations are presented in Table S4.

WWTP effluent comparison between four cities

In addition to the WWTP effluent samples from Halmstad (Västra Stranden) and Västerås (Kungsängen) presented in the previous sections, we also analysed WWTP effluent from Stockholm (Henriksdal), to cover potential emissions from use and waste handling, and from Skellefteå (Tuvan), as this is nearby Northvolt's gigafactory (sampled between 7-15th of April 2025 after the bankruptcy on the 12th of March). Samples were collected around the same period during winter/spring 2025 (exact sampling dates specified in Table S2).

Concentrations of PFAS and the inorganic fluorinated substances were comparable between the cities and BF_4^- and PF_6^- ranged from 50-117 ng/L and 74-114 ng/L, respectively (Figure 10). Previous studies reported PF_6^- levels of 20-102 ng/L in Swedish wastewaters (Tisler et al., 2025). BF_4^- and PF_6^- have been detected in a Swedish waste management facility at ca 4 500 and 2 000 ng/L, respectively (Pettersson et al., 2024).

TFA was the highest measured PFAS in all effluents ranging from 540 ng/L in Skellefteå to 1 074 ng/L in Stockholm. These concentrations are comparable to previous reports of TFA levels in Swedish WWTP effluents from 2022 which ranged from 362-797 ng/L (Haglund et al., 2023). PFPrA was measured at the highest concentrations in the effluent from Stockholm (64 ng/L), followed by Halmstad (50 ng/L), Västerås (27 ng/L) and Skellefteå (6 ng/L). Previous studies reported PFPrA levels of 68 ng/L in WWTP effluent from Borlänge and 18 ng/L in WWTP effluent from Stockholm in 2022 (Haglund et al., 2023).

TFMS levels were comparable to the previous reports and ranged from 3-8 ng/L between the four cities. ΣPFOS (L+br) levels were highest in Halmstad (32 ng/L) and were around 7-8 ng/L in the other cities. All effluents contained TFSI and concentrations ranged from 0.4-1.8 ng/L (Figure 10), which is similar to previous reported TFSI levels in Sweden (0-1.5 ng/L) (Tisler et al., 2025).

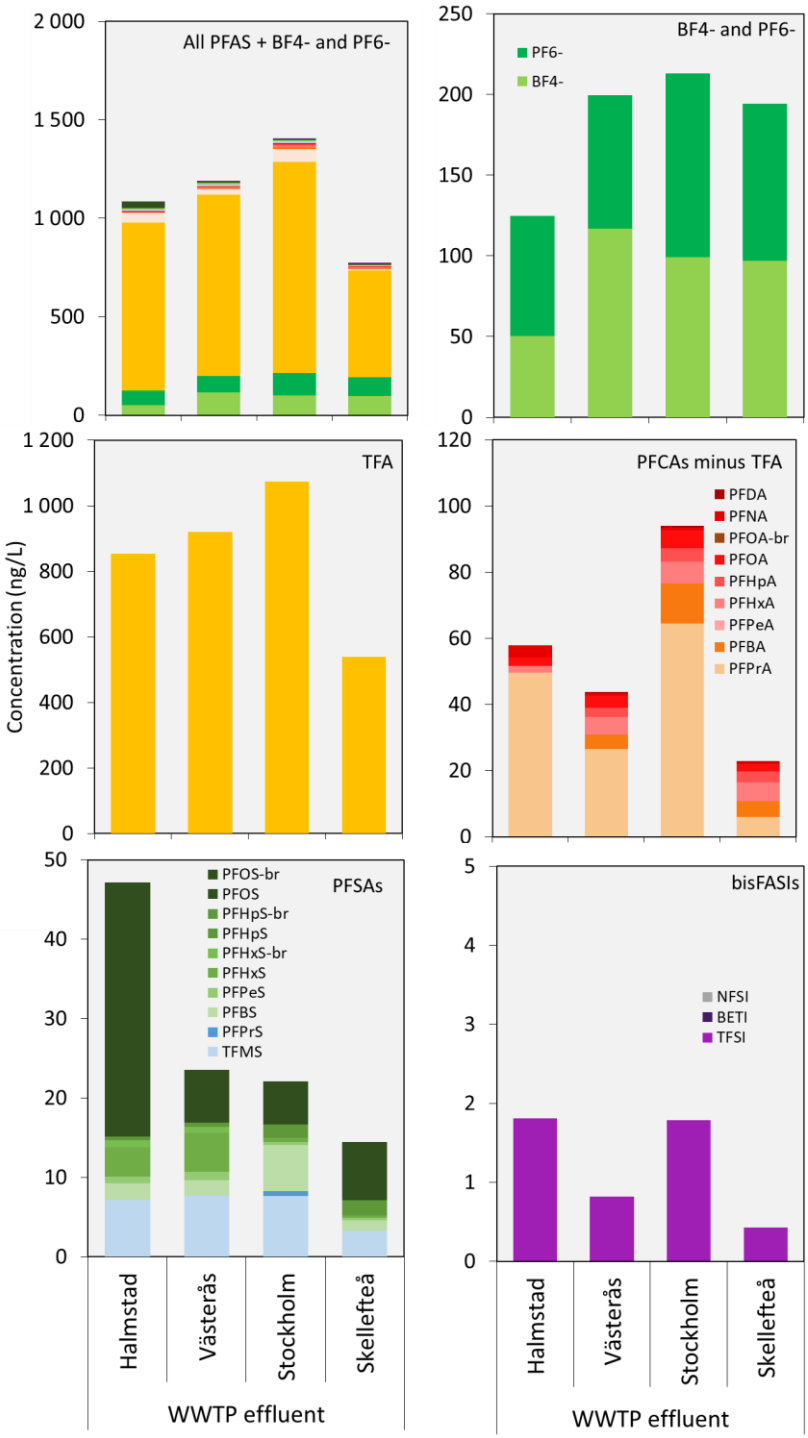

Figure 10. Concentrations (ng/L) in WWTP effluents from four cities.

Conclusions

This report shows that fluorinated substances that are known to be used in LIBs are detectable at elevated concentrations around a battery recycling and waste handling site in Sweden.

Two inorganic fluorinated anions, BF_4^- and PF_6^-, were detected in the majority of samples, with concentrations reaching up to approximately 2 400 ng/L and 39 000 ng/L respectively, near an industrial site and a landfill in Halmstad. These compounds are now confirmed to be widely present in surface water (Neuwald et al., 2021), WWTP effluent (Neuwald et al., 2023), water within a waste management facility (Pettersson et al., 2024), and drinking water (He et al., 2024; Jiao et al., 2023). However, knowledge on their toxicity and persistence is limited. Although humans will be directly exposed to these inorganic ions through consumption of drinking water there is no information regarding potential health risks. Furthermore, a recent study reported high bioconcentration factors (BCF) from water to rocket (*Eruca sativa*) leaves, suggesting that humans may be additionally exposed to these inorganic ions through crop consumption when surface water is used for irrigation (Seelig et al., 2025).

TFA was present in all analysed samples and made up the largest fraction among the target analytes, except in three cases where PF_6^- showed the highest concentrations (HA-4, HA-6, and LF-2). Of the bisFASIs, TFSI was the most prevalent in the samples. TFSI concentrations observed from the recycling centre emission point (82 ng/L; HA-4) were higher than the sampling point upstream (33 ng/L; HA-6) and lower than those observed further downstream in a nature reserve (106 ng/L; HA-7). TFSI was also detected in all four WWTP effluents included in this study at concentrations from 0.4-1.8 ng/L. In comparison, TFSI was previously detected in 22 of 30 samples in European wastewater at concentrations ranging from 0.4-12.7 ng/L (Tisler et al., 2025), and in three Italian E-waste recycling facilities (Barola et al., 2023). A recent study reported TFSI concentrations of 2 440 ng/L around a 3M manufacturing site in Minnesota and 82 ng/L at a 3M manufacturing site in Antwerp (Guelfo et al., 2024). Of the two other bisFASI homologues included in our target analysis, only BETI was detected and was present in samples from the Kistinge industrial area, around the recycling centre, and in the landfill leachate from an active landfill in the Stockholm area.

A few compounds (BF_4^-, TFMS, PFPrS, PFBS, PFHxS [L+br], TFSI) were detected at higher concentrations at the emission point of Stena Metall AB (HA-4) than in the sampling point upstream Kistingebäcken, closer to the landfill (HA-6), and are thus more likely to come from the recycling site. TFMS is also a fluorinated ionic liquid anion that is used in batteries. PFBS is commonly used in electronics (e.g., in semiconductors) as a replacement for PFOS (ChemSec, 2023). PFPrS was only detected in samples around the Kistinge industrial area and in the landfill leachate from the Stockholm area, and was not detected in any other surface water.

This study underscores the importance of including ionic liquids and short-chain PFAS in future environmental monitoring near lithium-ion battery recycling and electronic waste handling facilities, as identifying which fluorinated substances bypass current treatment processes is essential for enabling targeted mitigation by both industry and waste management operators.

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Supporting information

Table S1. List of target analytes, abbreviations, quantification and qualification ions, LC columns and internal standards (ISs).

Class	Analytes	CAS numbers (anions/acids)	Abbreviation	Molecular formula (anion)	Quantification ion	Qualification ion	LC column	Isotope-labelled IS	Quantification ion of IS
Inorganics	Tetrafluoroborate	14874-70-5 (anion)	BF_4^-	BF_4^-	87	-	Trinity	$^{13}C_2$-TFA	115>69
	Hexafluorophosphate	16919-18-9 (anion)	PF_6^-	PF_6^-	145	-	Trinity	$^{13}C_2$-TFA	115>69
PFCAs	Trifluoroacetic acid	76-05-1	TFA	CF_3COO^-	113>69	113>82	Trinity	$^{13}C_2$-TFA	115>69
	Perfluoropropanoic acid	422-64-0	PFPrA	$C_2F_5COO^-$	163>119	163>69	Trinity	$^{13}C_4$-PFBA	217>172
	Perfluorobutanoic acid	375-22-4	PFBA	$C_3F_7COO^-$	213>169	213>69	Trinity	$^{13}C_4$-PFBA	217>172
	Perfluoropentanoic acid	2706-90-3	PFPeA	$C_4F_9COO^-$	263>219	263>169	Trinity	$^{13}C_3$-PFPeA	268>223
	Perfluorohexanoic acid	307-24-4	PFHxA	$C_5F_{11}COO^-$	313>269	313>119	Atlantis	$^{13}C_2$-PFHxA	315>270
	Perfluoroheptanoic acid	375-85-9	PFHpA	$C_6F_{13}COO^-$	363>319	363>169	Atlantis	$^{13}C_4$-PFHpA	367>322
	Perfluorooctanoic acid	335-67-1	PFOA	$C_7F_{15}COO^-$	413>369	413>169	Atlantis	$^{13}C_4$-PFOA	417>372
	Perfluorononanoic acid	375-95-1	PFNA	$C_8F_{17}COO^-$	463>419	463>169	Atlantis	$^{13}C_5$-PFNA	468>423
	Perfluorodecanoic acid	335-76-2	PFDA	$C_9F_{19}COO^-$	513>469	513>169	Atlantis	$^{13}C_2$-PFDA	515>470
PFSAs	Trifluoromethane sulfonic acid	1493-13-6	TFMS[1]	$CF_3SO_3^-$	149>80	149>99	Trinity	$^{13}C_3$-PFBS	302>80
	Pentafluoroethanesulfonic acid	354-88-1	PFEtS	$C_2F_5SO_3^-$	199>80	199>99	Trinity	$^{13}C_3$-PFBS	302>80
	Perfluoropropane sulfonic acid	423-41-6	PFPrS	$C_3F_7SO_3^-$	249>80	249>99	Trinity	$^{13}C_3$-PFBS	302>80
	Perfluorobutane sulfonic acid	375-73-5	PFBS	$C_4F_9SO_3^-$	299>80	299>99	Trinity	$^{13}C_3$-PFBS	302>80
	Perfluoropentane sulfonic acid	2706-91-4	PFPeS	$C_5F_{11}SO_3^-$	349>80	349>99	Atlantis	$^{18}O_2$-PFHxS	403>84
	Perfluorohexane sulfonic acid	355-46-4	PFHxS	$C_6F_{13}SO_3^-$	399>80	399>99	Atlantis	$^{18}O_2$- PFHxS	403>84
	Perfluoroheptane sulfonic acid	375-92-8	PFHpS	$C_7F_{15}SO_3^-$	449>80	449>99	Atlantis	$^{13}C_4$-PFOS	503>80
	Perfluorooctane sulfonic acid	1763-23-1	PFOS	$C_8F_{17}SO_3^-$	499>80	499>99	Atlantis	$^{13}C_4$-PFOS	503>80
	Perfluorononane sulfonic acid	68259-12-1	PFNS	$C_9F_{19}SO_3^-$	549>80	549>99	Atlantis	$^{13}C_4$-PFOS	503>80
BisFASIs	Bisperfluoromethane sulfonimide	82113-65-3	TFSI[2]	$C_2F_6NS_2O_4^-$	280>147	280>78	Atlantis	$^{13}C_5$-PFPeA	268>223
	Bisperfluoroethanesulfonimide	152894-10-5	BETI[3]	$C_4F_{10}NS_2O_4^-$	380>197	380>78	Atlantis	$^{13}C_2$-PFHxA	315>270
	Bisperfluorobutanesulfonimide	39847-39-7	NFSI[4]	$C_8F_{18}NS_2O_4^-$	580>297	580>78	Atlantis	$^{13}C_4$-PFOS	503>80

[1]TFMS is also referred to in the literature as Triflate. [2]TFSI is also referred to as bisFMeSI, bistriflimide, or NTf_2. [3]BETI is also referred to as bisFEtSI. [4]NFSI is also referred to as bisFBSI.

Table S2. Overview on samples collected, including sample type, date and coordinates.

Location	Site ID	Sample description	Sample type	Sampling date	Coordinates
Halmstad	HA-0	Field blank Halmstad	MilliQ water	20250211	-
	HA-1	WWTP Västra Stranden outfall area – Nissan river	Surface water	20250211	56°39'29.9"N 12°50'59.3"E
	HA-2	WWTP Västra Stranden effluent (sampled at site by WWTP personnel)	WWTP effluent	20250210-20250217	56°39'42.9"N 12°50'57.5"E
	HA-3	Surface water northern Kistinge	Surface water	20250211	56°38'29.6"N 12°55'24.5"E
	HA-4	Kistingebäcken	Surface water	20250211	56°38'00.4"N 12°56'00.1"E
	HA-5	Upstream Kistingebäcken (before landfill)	Surface water	20250211	56°38'04.6"N 12°56'21.6"E
	HA-6	Downstream landfill	Surface water	20250211	56°38'09.2"N 12°56'51.9"E
	HA-7	Downstream Kistingebäcken + Trönningeån	Surface water	20250211	56°37'31.2"N 12°55'19.5"E
	HA-8	Trönningeån upstream of Kistingebäcken	Surface water	20250211	56°37'15.0"N 12°56'46.9"E
	HA-9	Trönningeån further upstream of Kistingebäcken (before Kronotorp landfill)	Surface water	20250211	56°37'25.8"N 12°57'47.5"E
	HA-10	Pond south of BRC	Surface water	20250211	56°37'45.9"N 12°56'12.7"E
	HA-11	Pond south of BRC	Surface water	20250211	56°37'47.2"N 12°56'21.9"E
	HA-12	Drinking water	Drinking water	20250211	56°39'03.9"N 12°52'50.8"E
	HA-13	Lake outside industry area	Surface water	20250211	56°40'25.8"N 13°03'54.7"E
Västerås	VÄ-0	Field blank Västerås	MilliQ water	20250217	-
	VÄ-1	Trench northeast of NV Labs	Storm water	20250217	59°38'30.5"N 16°35'29.4"E
	VÄ-2	Stream east of NV Labs (where 2 streams come together)	Surface water	20250217	59°38'16.9"N 16°36'30.8"E
	VÄ-3	Stream southeast of NV Labs (in the forest)	Surface water	20250217	59°38'07.7"N 16°36'31.5"E
	VÄ-4	Trench south of NV Labs (according to SR underlag 2024)	Surface water	20250217	59°38'12.6"N 16°35'44.9"E
	VÄ-5	Upstream Svartån (Rönnby)	Surface water	20250217	59°38'41.3"N 16°29'36.5"E
	VÄ-5	Discharge point into Svartån river (at Hovdestalund) from municipal stormwater (including from Finslätten industrial area)	Discharge water	20250217	59°37'59.7"N 16°30'22.8"E
	VÄ-6	Svårtån river downstream (Blåsbo)	Surface water	20250217	59°36'59.1"N 16°31'40.9"E
	VÄ-7	Svårtån river downstream before release to Lake Mälaren	Surface water	20250217	59°36'13.7"N 16°32'49.4"E
	VÄ-8	WWTP effluent Kungsängen	WWTP effluent	20250311-20250317	59°36'31.3"N 16°33'44.9"E
	VÄ-9	Drinking water	Drinking water	20250217	59°38'54.7"N 16°30'23.1"E
Stockholm	HE-1	WWTP effluent Henriksdal	WWTP effluent	20250224-20250302	59°18'35.6"N 18°06'33.5"E
	QC	Spegeldammen pond water for QC (sampled near Stockholm University)	Surface water	20250307	59°21'56.3"N 18°04'43.1"E
	LF-1	Landfill leachate from active landfill (Sofielund)	Landfill leachate	20250325	59°10'50.3"N 18°00'43.8"E
	LF-2	Surface water after utjämningsmagasin (Sofielund landfill)	Surface water	20250325	59°11'16.5"N 18°00'15.8"E
Skellefteå	SK-1	WWTP effluent Tuvan	WWTP effluent	20250407-20250415	64°43'23.1"N 21°03'23.3"E

Table S3. Mobile phase gradient programs used for the different columns.

Column	Time (min)	Proportion of B (%)
Trinity[1] (Flow rate 0.3 mL/min)	0	20
	0.25	20
	10	95
	14	95
	15	20
	17.5	20
Atlantis C18[2] (Flow rate 0.3 mL/min)	0	1
	2	1
	3	25
	8	50
	15	85
	16	100
	20	100
	20.1	0
	23.5	0

[1]Trinity mobile phase A: water containing 20 mM ammonium acetate and mobile phase B: Methanol/water (99:1, v/v) containing 20 mM ammonium acetate.

[2]Atlantis C18 mobile phase A: Water containing 2 mM ammonium acetate and mobile phase B: Methanol containing 60 mM ammonium hydroxide.

Table S4. Concentrations (ng/L) in all samples. IDs are specified in Table S2. LOQs are defined as the lowest calibration point, based on a sample volume of 250 mL. “nd” = not detected. “cont.” = contaminated.

LOQ (ng/L)	0.906	0.305	15.0	0.406	0.398	1.136	0.075	0.075	0.075	0.075	0.075	0.075	1.217	0.154	0.051	0.006	0.004	0.004	0.019	0.019	0.062	0.062	0.019	0.019	0.031	0.032	0.031
Sample ID	BF_4^-	PF_6^-	TFA	PFPrA	PFBA	PFPeA	PFHxA	PFHpA	PFOA	PFOA-br	PFNA	PFDA	TFMS	PFPrS	PFBS	PFPeS	PFHxS	PFHxS-br	PFHpS	PFHpS-br	PFOS	PFOS-br	PFNS	PFNS-br	TFSI	BETI	NFSI
HA-0	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.1	nd	nd	nd	nd	nd	nd	nd	nd
HA-1	31.8	nd	633	nd	nd	nd	nd	nd	0.6	nd	0.2	0.2	nd	nd	nd	nd	1.2	0.2	0.8	0.7	60.7	37.4	nd	nd	<LOQ	nd	nd
HA-2a	55.5	71.8	828	50.5	nd	nd	2.7	nd	1.9	nd	2.5	nd	6.8	Nd	2.1	0.8	3.5	0.7	nd	nd	3.4	3.0	nd	nd	1.5	nd	nd
HA-2b	50.0	83.6	978	50.4	nd	nd	3.3	nd	3.3	nd	4.0	nd	7.4	nd	2.1	0.7	3.4	0.8	0.6	0.4	23.7	18.4	nd	nd	1.8	nd	nd
HA-2c	46.0	67.3	756	48.2	nd	nd	nd	nd	2.5	nd	4.4	nd	7.3	nd	2.0	1.1	4.3	1.1	0.5	nd	27.9	19.5	nd	nd	2.1	nd	nd
HA-3	nd	38.9	964	4.0	2.3	nd	1.2	1.3	2.9	0.2	0.2	<LOQ	1.6	nd	1.1	0.2	2.6	0.3	0.1	0.3	1.0	2.0	nd	nd	0.1	nd	nd
HA-4a	798	12500	3010	87.4	75.1	48.5	80.5	44.0	84.8	13.9	2.8	0.6	399	30.5	1330	9.4	30.6	6.5	1.0	1.0	16.4	15.7	nd	nd	88.2	0.5	nd
HA-4b	1080	7340	3010	86.7	81.2	60.8	94.3	44.8	80.5	12.6	2.7	0.7	545	19.9	1320	8.6	32.1	5.6	1.1	1.0	17.7	15.7	nd	nd	95.6	0.6	nd
HA-4c	1000	7020	2930	78.0	65.8	90.6	77.0	51.0	80.0	11.6	2.7	0.7	523	24.0	1200	8.3	32.3	5.9	1.0	1.0	15.3	15.0	nd	nd	63.2	0.5	nd
HA-5	2350	3320	3020	216	82.1	89.8	89.1	48.5	81.0	10.8	2.8	0.8	223	11.8	959	9.8	1.2	0.9	34.1	6.3	25.5	21.3	nd	nd	75.0	0.6	nd
HA-6	66.0	38900	3760	20.8	46.8	14.1	59.5	61.1	250	26.9	4.1	1.3	9.1	7.6	392	25.0	1.8	0.8	63.9	16.2	15.3	15.2	nd	nd	32.8	0.1	nd
HA-7	394	1320	1240	38.7	9.1	26.5	11.7	5.5	9.0	1.1	0.4	0.2	116	0.7	292	0.9	0.2	0.2	3.7	0.6	3.3	2.8	nd	nd	106	0.1	nd
HA-8	3.9	44.0	1550	3.9	nd	nd	0.8	0.6	0.5	nd	nd	nd	1.7	nd	0.4	0.3	0.1	<LOQ	0.7	0.2	1.1	1.1	nd	nd	<LOQ	nd	nd
HA-9	1.9	15.0	1220	3.1	nd	nd	1.0	nd	0.8	nd	nd	0.2	2.7	nd	0.4	0.1	0.1	nd	0.3	nd	0.5	0.5	nd	nd	0.1	nd	nd
HA-10	27.2	54.2	1600	24.1	18.8	5.5	5.2	3.6	6.9	0.4	1.1	0.4	5.9	0.4	37.4	0.3	0.2	0.2	4.0	0.6	5.4	4.6	nd	nd	2.7	nd	nd
HA-11	5.9	29.6	2160	14.0	28.6	nd	12.4	11.3	25.9	1.2	4.7	1.3	4.8	nd	7.1	0.9	8.9	1.2	0.8	1.0	cont.	cont.	nd	nd	0.9	nd	nd
HA-12	nd	<LOQ	460	1.2	nd	nd	nd	nd	nd	nd	nd	nd	<LOQ	nd	0.1	nd	0.3	0.1	0.1	0.2	14.0	7.0	nd	nd	nd	nd	nd
HA-13	42.4	431	716	1240	13.7	41.7	22.4	4.3	1.7	nd	nd	nd	nd	nd	1.2	nd	0.3	nd	nd	nd	cont.	cont.	nd	nd	0.3	nd	nd
VÄ-0	Nd	Nd	nd	Nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	3.9	nd	2.6	3.5	cont.	cont.	nd	nd	nd	nd	nd
VÄ-1	nd	<LOQ	512	Nd	nd	nd	nd	nd	0.8	nd	nd	nd	nd	nd	0.6	nd	nd	nd	nd	nd	cont.	cont.	nd	nd	<LOQ	nd	nd
VÄ-2	38.6	386	799	61.5	nd	nd	31.7	nd	19.4	nd	nd	nd	<LOQ	nd	0.8	1.3	nd	nd	nd	nd	cont.	cont.	nd	nd	nd	nd	nd
VÄ-3	136	4.5	1390	Nd	nd	nd	nd	nd	nd	nd	nd	nd	2.9	nd	1.4	nd	1.0	1.0	<LOQ	1.3	cont.	cont.	nd	nd	nd	nd	nd
VÄ-4	9.8	34.9	2360	37.6	23.7	nd	nd	nd	nd	nd	nd	nd	4.4	nd	3.3	nd	10.0	2.6	9.1	6.4	cont.	cont.	nd	nd	nd	nd	nd
VÄ-5	9.0	30.2	909	6.3	3.2	nd	nd	nd	nd	nd	nd	nd	3.0	nd	0.6	nd	nd	nd	nd	nd	cont.	cont.	nd	nd	nd	nd	nd
VÄ-6	4.3	2.2	693	Nd	nd	nd	2.2	nd	2.4	nd	nd	nd	nd	nd	0.7	nd	1.5	0.4	1.2	0.9	cont.	cont.	nd	nd	0.1	nd	nd
VÄ-7a	3.8	1.6	728	3.8	nd	nd	nd	nd	nd	nd	nd	nd	1.7	nd	nd	nd	nd	nd	nd	nd	cont.	cont.	nd	nd	nd	nd	nd
VÄ-7b	3.8	2.4	784	5.4	nd	nd	nd	nd	nd	nd	nd	nd	2.1	nd	nd	nd	nd	nd	nd	nd	cont.	cont.	nd	nd	nd	nd	nd
VÄ-7c	4.4	2.3	871	6.2	nd	nd	nd	nd	nd	nd	nd	nd	2.2	nd	nd	nd	2.9	0.8	3.4	1.9	cont.	cont.	nd	nd	nd	nd	nd
VÄ-8	117	82.4	921	26.5	4.4	nd	5.3	2.9	3.6	nd	0.7	0.4	7.7	nd	2.0	1.0	4.9	0.8	0.2	0.4	3.1	3.6	nd	nd	0.8	nd	nd
VÄ-9	26.6	2.6	702	12.0	6.5	nd	1.4	1.5	1.6	nd	nd	nd	2.4	nd	1.3	0.2	1.1	0.2	nd	nd	cont.	cont.	nd	nd	0.1	nd	nd
LF-1	178	886	19800	18300	2470	760	809	780	2050	114	155	78.7	776	68.1	2130	83.6	148	38.4	9.9	4.5	cont.	cont.	3.4	nd	329	3.9	nd
LF-2	878	3090	1100	571	65.1	180	76.9	30.8	27.4	1.7	3.0	3.1	211	3.4	30.6	2.3	10.2	1.8	0.7	nd	12.0	10.5	nd	nd	25.8	<LOQ	nd
HE-1	99.1	114	1070	64.5	12.1	nd	6.7	4.0	5.4	nd	0.8	0.5	7.6	0.6	5.8	0.4	0.6	nd	1.5	0.3	2.8	2.6	nd	nd	1.8	nd	nd
TU-1	97.1	97.1	540	6.0	4.8	nd	5.7	3.3	2.2	nd	0.7	0.2	3.3	nd	1.3	0.3	0.3	nd	1.9	nd	3.5	3.8	nd	nd	0.4	nd	nd
QC-no spike1	20.5	17.0	1450	12.9	19.4	nd	7.4	4.4	5.5	nd	nd	nd	3.2	nd	2.3	0.5	1.4	nd	2.9	nd	2.6	3.8	nd	nd	nd	nd	nd
QC-no spike2	23.9	13.4	1340	10.5	21.6	nd	7.6	3.2	4.7	nd	nd	nd	3.9	nd	1.9	0.6	<LOQ	nd	1.9	nd	2.3	2.9	nd	nd	nd	nd	nd
QC-no spike3	25.7	21.7	1380	11.5	15.1	nd	6.1	3.2	3.6	nd	nd	nd	3.3	nd	2.2	0.8	0.6	nd	1.9	nd	4.3	4.2	nd	nd	nd	nd	nd

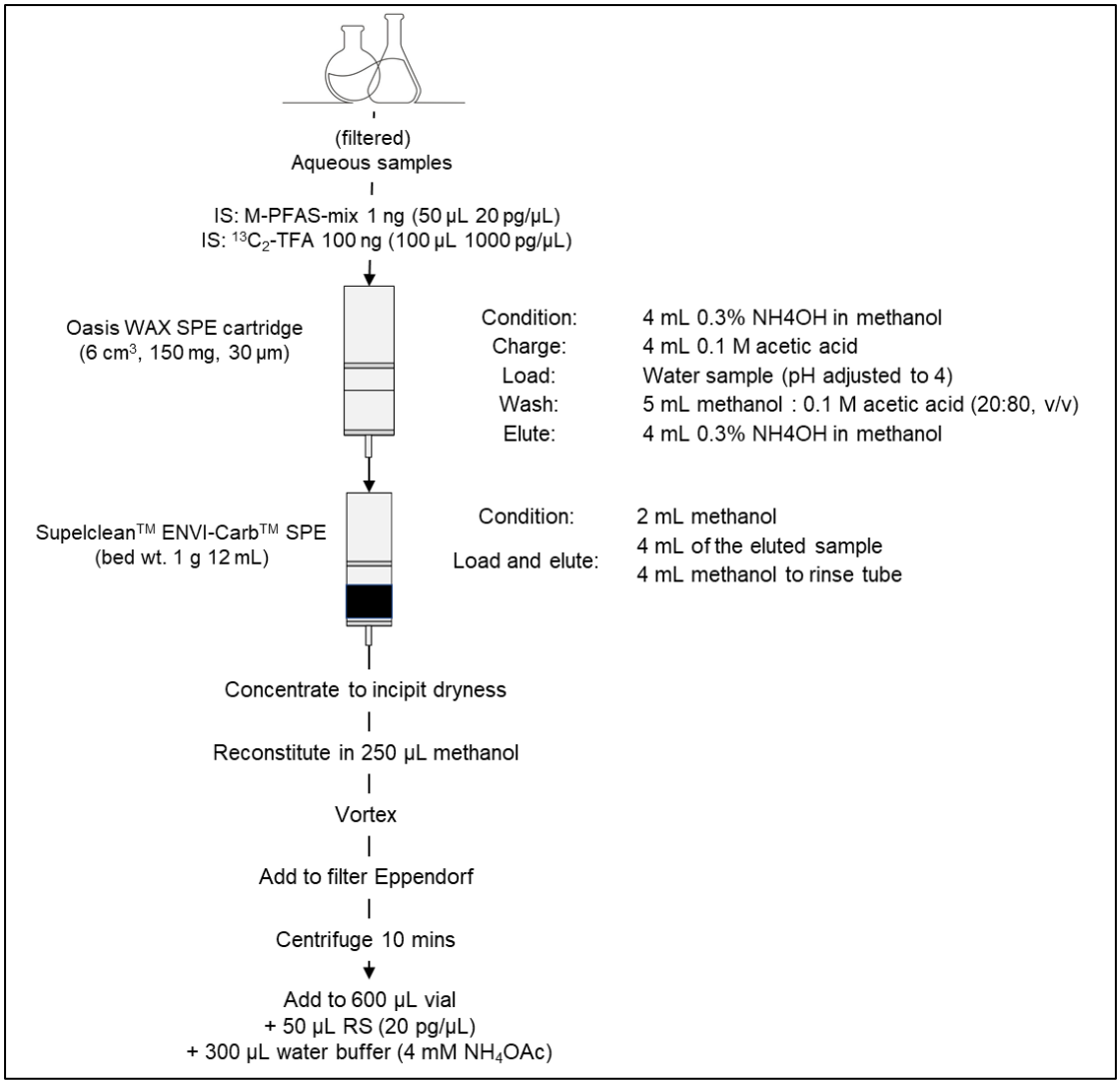

Figure S1. Schematic overview of the extraction.

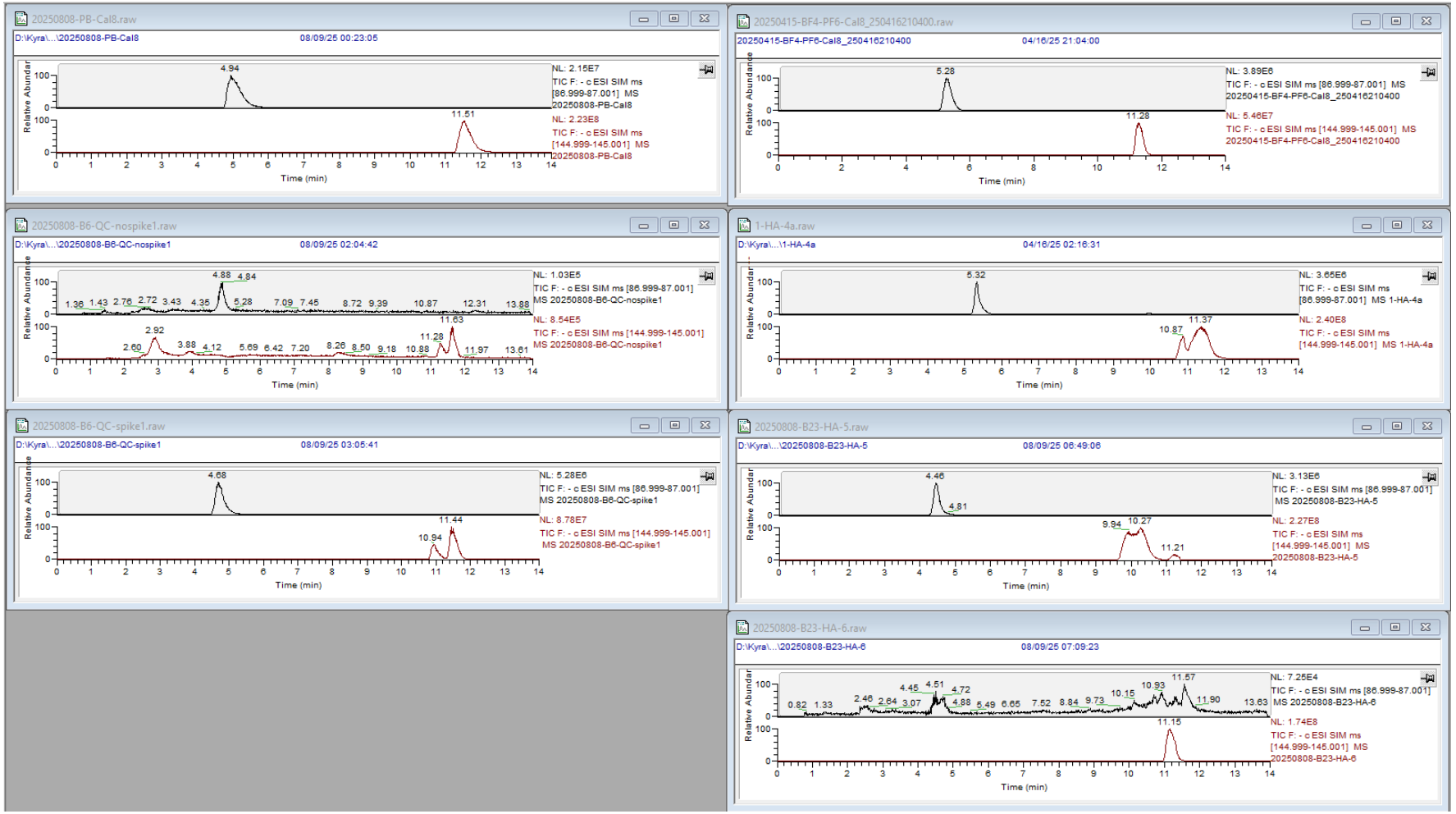

Figure S2. Extracted ion chromatograms for BF_4^- (top), and PF_6^- (bottom). Double peaks were observed in a few samples, QC unspiked and spiked, HA-4, HA-5, and HA-6 are shown here, together with two calibration standards (run on different days). In the QC sample (surface water) the unspiked sample showed double peaks for PF_6^- (the first one eluting earlier compared to the calibration standard) and both peaks increased similarly in the spiked sample, which might indicate both peaks belong to PF_6^-.