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PFAS Contamination in Europe: Generating Knowledge and Mapping Known and Likely Contamination with "Expert-Reviewed" Journalism

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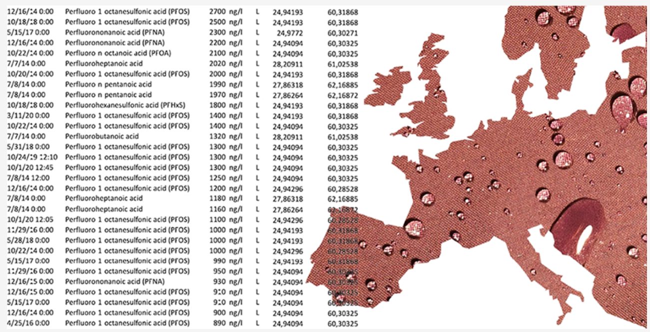

ABSTRACT: While the extent of environmental contamination by per- and polyfluoroalkyl substances (PFAS) has mobilized considerable efforts around the globe in recent years, publicly available data on PFAS in Europe were very limited. In an unprecedented experiment of "expert-reviewed journalism" involving 29 journalists and seven scientific advisers, a cross-border collaborative project, the "Forever Pollution Project" (FPP), drew on both scientific methods and investigative journalism techniques such as open-source intelligence (OSINT) and freedom of information (FOI) requests to map contamination across Europe, making public data that previously had existed as "unseen science". The FPP identified 22,934 known contamination sites, including 20 PFAS manufacturing facilities, and 21,426 "presumptive contamination sites", including 13,745 sites presumably contaminated with fluorinated aqueous film-forming foam (AFFF) discharge, 2911 industrial facilities, and 4752 sites related to PFAS-containing waste. Additionally, the FPP identified 231 "known PFAS users", a new category for sites with an intermediate level of evidence of PFAS use and considered likely to be contamination sources. However, the true extent of contamination in Europe remains significantly underestimated due to a lack of comprehensive geolocation, sampling, and publicly available data. This model of knowledge production and dissemination offers lessons for researchers, policymakers, and journalists about cross-field collaborations and data transparency.

KEYWORDS: *per- and polyfluoroalkyl substances (PFAS), PFAS contamination, PFAS testing and investigation, Europe, known PFAS users, expert-reviewed journalism*

■ INTRODUCTION

The entire Earth is contaminated by per- and polyfluoroalkyl substances (PFAS),[1−3] yet for most places, monitoring data are nonexistent, limited, or difficult to access. This article reports on the methodology for a Europe-wide estimation of PFAS contamination locations,[4] based on and adding to existing models for uncovering and estimating known and suspected PFAS sites. PFAS are a class of over 12,000 synthetic organic chemicals of concern.[5] This concern is driven by their extreme persistence[6] but also by the toxicity, bioaccumulation potential, mobility, and even global warming potential of various PFAS.[7] These so-called "forever chemicals" are widely used in hundreds of consumer products and industrial applications such as nonstick and high-temperature resistant coatings, firefighting foams, and stain-resistant and waterproofing treatment.[8] PFAS have been linked to many health effects, including several types of cancers, liver impacts, adverse reproductive and developmental effects, thyroid impacts, and altered immune function. The broad social costs of PFAS contamination are externalized onto the public and governments,[9] generating a heavy burden on society with estimations of $62.6 billion in annual healthcare costs in the US and as much as $16 trillion in annual healthcare and remediation costs globally.[10,11]

PFAS have been broadly detected in environmental media including surface water, groundwater, raw and finished drinking water, soil, air, landfill leachate, sewage sludge, food, and dust.[12−15] As examples, a recent analysis of tap water samples in the United States collected between 2016 and 2021

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detected PFAS at 45% of tested locations,[16] and the 2019 French National Biomonitoring Programme measured serum levels of 17 PFAS and detected PFAS in 100% of the 993 participants.[17] It has been argued that PFAS have exceeded a "planetary boundary" of "widespread and poorly reversible risks associated even with low-level PFAS exposures" since global rainwater samples have PFAS levels above proposed regulatory limits designed to protect public health.[1]

The amount of PFAS environmental sampling has increased substantially over the past decade, but major gaps remain in testing, such that known contamination "underrepresents the scope of contamination and is biased toward locations with rigorous testing programs".[18] To allow decision-makers to identify locations where PFAS contamination is likely, the "presumptive PFAS contamination" approach argues that, in the absence of high-quality testing data to the contrary, PFAS contamination should be presumed at fluorinated aqueous film-forming foam (AFFF) discharge sites, certain industrial facilities, and sites related to PFAS-containing waste.[18]

In addition to data gaps due to a lack of testing, the present study was motivated by two additional data gaps. First, unlike in the US where many PFAS testing datasets have been made public by federal and state governments, academic research groups, and environmental advocacy organizations,[19−22] there were very few publicly available data on PFAS contamination across the EU. Second, in most cases, legal protections for industry trade secrets and confidential business information prevent the public from knowing where PFAS are used and emitted.[23,24] An exception to this is the US Toxics Release Inventory program, which has required reporting since 2020 by some firms in a subset of industries for a small number of PFAS.[25] But in most cases, even if a specific company is known to produce and/or use PFAS, it is difficult or impossible for the public to know whether PFAS are used at individual facilities.

■ EUROPEAN UNION CONTEXT

Despite its 2007 Regulation on the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH),[26] considered a pioneering chemicals regulation, the European Union (EU) does not systematically collect comprehensive environmental contamination data on any environmental chemicals, including PFAS.[27] The European Environment Agency (EEA) collects in the European Pollutant Release and Transfer Register (E-PRTR) annual emissions data requested under the Industrial Emissions Directive from the 60,000 largest industrial complexes from 65 economic activities in the 27 EU Member States as well as Iceland, Liechtenstein, Norway, Serbia, Switzerland, and the United Kingdom.[28] However, PFAS are not included in the E-PRTR's 91 pollutants from seven groups (greenhouse gases, other gases, heavy metals, pesticides, chlorinated organic substances, other organic substances, and inorganic substances) for which emissions data are collected and available.

There are currently no specific or overarching regulations targeting PFAS emissions or production in the EU, although drinking water monitoring requirements have been developed. According to the revised 2020 Drinking Water Directive,[29] all EU Member States will have to monitor 20 PFAS of concern ("PFAS sum") and/or the total amount of PFAS ("PFAS Total") in water intended for human consumption by January 2026. PFAS are not mentioned in either the 2010 EU Directive on Industrial Emissions,[30] which regulates emissions through permits, or in the 2000 EU Water Directive, which regulates emissions to water.[31] Few regional or national regulations exist in European countries related to PFAS emissions or monitoring. In The Netherlands, for example, the local body DCMR Milieudienst Rijnmond issues PFAS emission permits to the Chemours (formerly DuPont) PFAS facility in Dordrecht.[32]

In early 2023, the European Chemicals Agency (ECHA) published a PFAS "universal restriction" proposal prepared and submitted by four EU Member States (Denmark, Germany, The Netherlands, and Sweden) and Norway, which would effectively ban 10,000 PFAS in the EU by 2026−2027.[33] ECHA has also been reviewing a restriction on all PFAS in firefighting foams since February 2022.[34] ECHA estimated that around 4.4 million metric tons of PFAS "would end up in the environment over the next 30 years unless action is taken".[33] If adopted, both restrictions would represent the broadest chemical ban in history and could create a precedent for other chemical classes, such as brominated flame retardants, bisphenols, or phthalates. Chemical regulation in the US and EU is typically chemical-by-chemical, with limited exceptions such as polychlorinated biphenyls (PCBs) under the Toxic Substances Control Act or the Montreal Protocol's restriction of ozone-depleting chlorofluorocarbons.[35] In the EU, manufacturers must register chemicals with ECHA by filing a "registration dossier".[36] The information requirement applies only to registrants manufacturing or importing a substance in quantities greater than 10 metric tons a year and further varies according to tonnage. Dossiers include company names and postal addresses but not the precise location(s) where chemical manufacturing occurs. For example, the Belgian chemical company Solvay operates 12 manufacturing facilities across Europe, but their registrations for PFAS are made under only one entity "Solvay Specialty Polymers Italy".[37]

Given this scientific and regulatory context, understanding the scale of known and potential PFAS contamination in all of the global regions is essential. No systematic compilation of PFAS facility locations or monitoring data existed for the EU. The cross-border collaborative project "Forever Pollution Project" (FPP) was formed to fill this gap.

■ METHODS

The FPP started in April 2022 with five journalists based in countries where PFAS facilities had been located through previous research: Belgium, France, Germany, Italy, and The Netherlands.[38] The initial goal was to locate all PFAS manufacturing facilities in Europe, based on the estimation by Goldenman et al. (2019) that there could be between 12 and 20.[39] The project later scaled up in ambition both in terms of data collection and in the number of participating journalists and scientists to ultimately include multiple categories of PFAS sites in the EU, in the United Kingdom (UK), and in countries of the European Economic Area and the European Free Trade Association (EFTA), namely, Norway, Iceland, Liechtenstein, and Switzerland. The core mapping effort was led by the French newspaper Le Monde. The FPP ultimately included EU-wide geolocation of three categories of PFAS contamination: known PFAS contamination sites based on existing testing data; presumptive PFAS contamination sites based on an existing model for where contamination should be presumed in the absence of existing testing; and a new category of "known PFAS users" to capture facility locations where PFAS were manufactured and/or used in ways expected

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to result in local emissions but that lacked available testing data.

The FPP team also convened an advisory board of PFAS scientists representing multiple disciplines and geographic locations, a form of "expert-reviewed journalism" we describe in greater detail below.[38] "Cross-field collaborations" involving journalists with civil society organizations such as NGOs, universities or civic tech groups have developed significantly in the past years.[40] However, journalistic projects aiming at generating data in collaboration with scientists rather than reporting on already-produced data are not common.

Identifying PFAS Sites in the EU. We systematically gathered all available data sets of PFAS sites in the EU, including known contaminated sites with existing monitoring data, presumptive contamination sites following Salvatore et al.'s model, and a new category of "known PFAS users".[18]

Known Contamination Sites. We defined known contamination sites as locations where PFAS have been detected with water or solids testing above 10 ng/L or 10 ng/kg, respectively (or above the limits of detection and/or limit of quantification for datasets with higher limits). Because the goal was to assemble all available data on PFAS sampling, the known contamination site compilation does not distinguish PFAS contamination due to proximate point-source emissions from contamination from PFAS deposition or more general sources.[1] We collected over 100 PFAS monitoring datasets from 137 organizations across Europe, including national and local authorities, regulatory agencies, research institutes, universities, and scientific research teams.[41] We obtained these data sets through publicly available websites, direct communications, and, when data were not publicly available, through freedom of information (FOI) requests. In the UK, the Watershed journalists collected 45 tap or surface water samples at locations chosen because they were close to potential sources of PFAS pollution, such as military bases, situated in drinking water source protection zones, or proximate to PFAS manufacturing facilities. The journalists used PFAS-free polyethylene sampling bottles provided by the laboratory and followed laboratory-defined protocols to prevent the cross-contamination of samples. Samples were analyzed by Manchester Metropolitan University and the University of Greenwich.

In addition to sites with existing testing data, we assumed that all PFAS chemical manufacturing facilities emit or have emitted PFAS, even if no publicly available testing data exist. We therefore included them as known contamination sites. We defined a PFAS manufacturing facility as a plant that synthesizes PFAS to use on site and/or to sell to downstream users.

To locate PFAS manufacturers, we used a wide variety of sources, mainly open-source intelligence (OSINT), including websites, public databases, academic publications, gray literature, satellite imagery, and social media content, which are increasingly common data sources for investigative journalists, yet are not all well understood outside journalistic circles.[42] The OSINT sources included a list of PFAS registrants provided at our request by ECHA, trade associations member companies, corporate material (companies' websites, annual and sustainable development reports, financial and tax documents, safety and product data sheets, and certificates of registration), a list we assembled of fluoropolymer and fluoroelastomer trade names, litigation and internal corporate documents, Google Maps (www.googlemaps.com), consultant intelligence reports, scientific articles, and FOI material.[43,44] (The European Chemical Industry Council, Cefic, has created two product-defense groups: FluoroProducts and PFAS for Europe [FPP4 EU], and the European FluoroCarbons Technical Committee [EFCTC]; and Plastics Europe has created the Plastics Europe Fluoropolymers Products Group [FPG]. Within the US American Chemistry Council [ACC], two groups have replaced the late Fluorocouncil: Alliance for Telomer Chemistry Stewardship [ATCS], and Performance Fluoropolymer Partnership [PFP].) After identifying PFAS manufacturing facility locations, we sent right-to-reply emails to all 20 identified companies (responsible for 25 sites) for confirmation between October and December 2022 and 17 replied. Confirmations, negations, and clarifications led us to exclude five locations.

Presumptive Contamination Sites. Salvatore et al. (2022) defined presumptive PFAS contamination sites as locations where high-quality testing for PFAS is not available, but which can be presumed to be contaminated on the basis of scientific investigations and expert advice.[18] We based our research on the same methodology and three categories: (1) fluorinated aqueous film-forming foam (AFFF) discharge sites; (2) certain industrial facilities; and (3) sites related to PFAS-containing waste. For presumptive contamination sites and known PFAS users (described below), our analysis does not differentiate based on magnitude of potential or likely contamination. Consistent with prior studies identifying PFAS contaminated sites,[18,45,46] our goal is to identify point locations where PFAS have likely been used and/or released, thus leading to concerns about likely contamination.

Fluorinated AFFF Discharge and Storage Sites. Military Sites. Military sites were all presumed to have discharged fluorinated AFFF as part of training, testing, or the response to fire incidents. To locate military bases, military air bases and airports, military training camps, NATO bases, formerly used defense sites, military training grounds, military depots, military schools, and military airfields such as the ones used by the U.S. Air Force in Europe, we used a variety of OSINT sources including the Ministries of Defense, the Armed Forces, airports, Forgotten Airfields, Foursquare, Wikimapia, Wikipedia, documents by the German Landtage and Bundestag, websites of NATO, Metar-Taf.com, Military History Fandom, Dutch Aviation Society, GlobalSecurity.org. We excluded locations that would be unlikely to store AFFF due to the nature of their activities, such as military archives.

Commercial Civilian Airports. We used the OurAirports online database to identify all commercial civilian airports in the EU.[46] Following expert advice from ECHA, we excluded small airports and heliports and selected only large and medium airports as well as 102 closed airports with an asphalted runway. Many small airports and heliports are linked to hospitals or private establishments such as luxury resorts and therefore would not necessarily be testing and training with fluorinated AFFF nor play a major role as sources of contamination in the case of fire incidents.

Firefighting Training Sites and Firefighting Foam Incidents. There is no comprehensive database of firefighting training sites and incident sites for all of Europe. We found and included two data sets listing a subset of firefighting training sites, as well as firefighting foam incidents in Sweden (n = 10,774)[47] and Flanders (n = 279).[48] The Norwegian

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Environmental Agency Miljødirektoratet has located 246 firefighting training sites in the country.[49]

AFFF Sites without Mapping Information. According to ECHA, "there are over 50,000 public fire brigades in the EU, excluding those covering airports and private brigades covering industrial risks".[50] However, as there is no EU database of training centers for municipal fire brigades (departments), we were unable to include them. Likewise, there is no comprehensive database of fire suppression locations (such as airplane and railroad crash sites, oil and gas extraction sites, petroleum refineries, bulk storage facilities, and chemical manufacturing plants). Petroleum refineries, bulk storage facilities, and chemical manufacturing plants were included as industrial facilities (see below). Other facilities' locations could not be mapped.

Certain Industrial Activities. Salvatore et al. used the North American Industry Classification System (NAICS) to identify industrial activities that other academic studies and regulatory processes have identified as PFAS users and contamination sources.[51] They developed a single set of 38 NAICS codes using 11 regulatory or academic lists linking PFAS contamination with specific facility types and geolocated facilities identified by those NAICS codes.[18] We cross-matched these codes with the equivalent classification system in Europe, the European Nomenclature of Economic Activities (NACE),[52] using Glüge et al. (2020) on PFAS uses[8] and Goldenman et al.[39] as confirming documentation. This produced a list of 29 industrial activities that could be considered to be presumptive contamination sites in Europe. Unfortunately, the NACE system does not include geolocation data, and there are no centralized geolocation databases for most industrial activities in Europe. To get around this difficulty, we combined the 29 NACE codes with data from the above-mentioned E-PRTR,[53] which contains its own activities labels as well as geolocation data for the largest emitting industrial sites in Europe, required to operate in accordance with a permit and listed under Annex I of the Industrial Emissions directive.[30] After resolving several overlaps in industrial activity descriptions, 18 industrial sectors featured in the E-PRTR were categorized as presumptive contamination sites (see Supporting Information Tables S-1−S-3). E-PRTR geolocation data are limited to only large emitters, making our geolocation of most of these 18 industrial sectors a significant undercount. For one of the sectors, paper mills, we were able to identify a comprehensive list because of their relatively small number and the availability of OSINT (NACE codes C17.1 "Manufacture of pulp, paper, and paperboard" and C17.2 "Manufacture of articles of paper and paperboard"). We scraped the websites of the 18 national trade associations for the pulp and paper industry, members of the Confederation of European Paper Industries (Cepi),[54] to obtain the list and the addresses of companies.[53] GPS coordinates for each location were obtained by geocoding postal addresses using the Google Maps API. Locations were checked and corrected manually when the addresses lacked a street number or were related to a post box.

Sites Related to PFAS-Containing Waste. We identified wastewater treatment plants (WWTPs) from the European data set "Urban Waste Water Treatment Directive, Agglomerations",[55] which contains 25,738 WWTPs, most of which have a generated load of at least 2000 population equivalent. We filtered the data set to include 2,620 WWTPs treating a minimum average of 3700 m^3 per day. Second, both landfills for nonhazardous and hazardous waste and incinerators were identified by matching NACE codes E38.2.1 (Treatment and disposal of nonhazardous waste) and E38.2.2 (Treatment and disposal of hazardous waste) and E 37.00 (Sewerage) with the E-PRTR classification.

"Known PFAS Users", a New Category of Contamination Sites. During our research, we identified facilities for which we found concrete evidence of PFAS use, but that had no PFAS sampling data and were not PFAS manufacturers and therefore could not be categorized as known contamination sites. For these facilities, a designation of "presumptive" was insufficient based on the certainty of PFAS use, yet no testing data exist to document environmental levels and warrant a "known" designation. To better characterize these sites, we created a third category of "known PFAS users", facilities for which there is strong evidence of PFAS use but no testing data. As examples, AFFF manufacturers use PFAS to produce certain firefighting foams, and some industries buy fluoropolymers in the form of pellets or emulsions to manufacture their own branded products. Fluoropolymers fit within the OECD definition of PFAS, as well as the definition used in many pieces of PFAS legislation in the US. Fluoropolymers are also included in the EU's proposed universal restriction.[33] Beyond identifying the facility type, we do not differentiate known PFAS users based on the type or magnitude of PFAS releases.

As a starting point to identify known PFAS users, we used a list of over one hundred potential PFAS producers and users in the world developed through prior research initiatives.[56] Those and additional facilities were added as known PFAS users if they were verified through other publicly available sources, mainly OSINT resources. We located additional fluorocarbon manufacturers from "The List by INDITEX", a document developed by the fashion group Inditex which classifies chemicals used for textile and leather manufacturing processes.[57] We located facilities manufacturing Class B AFFF based on the ECHA restriction report on firefighting foams,[50] a 2015 Swedish Chemicals Agency (KEMI) survey,[58] and a 2018 report on fluorine-free firefighting foams published by the International Pollutants Elimination Network (IPEN).[59] We located dozens of facilities using polytetrafluoroethylene (PTFE), a synthetic fluoropolymer with numerous applications, by searching "PTFE" in Google Maps and then confirming that the mapped facility was a PFAS user with OSINT.

"Expert-Reviewed Journalism". In an unprecedented experiment of "expert-reviewed journalism", the journalists discussed and validated all major decisions and choices on the mapping work with an informal advisory group of seven experts. The continued dialog included social scientists Alissa Cordner (Whitman College, Walla Walla, USA) and Phil Brown (Northeastern University, Boston, USA); environmental scientists Derrick Salvatore (Massachusetts Department of Environmental Protection, USA), Kimberly K. Garrett (Northeastern University, Boston, USA), Ian Cousins (Stockholm University, Sweden), and Martin Scheringer (ETH Zürich, Switzerland); and environmental lawyer and consultant Gretta Goldenman (Global PFAS Science Panel, Belgium). As examples, the project's "expert-reviewers" were solicited to help distinguish PFAS manufacturing facilities from PFAS *users;* to determine which PFAS of interest would be shown on our interactive map, as the tool could only display contamination levels for six (perfluorooctanesulfonate [PFOS], perfluorooctanoic acid [PFOA], perfluorononanoic

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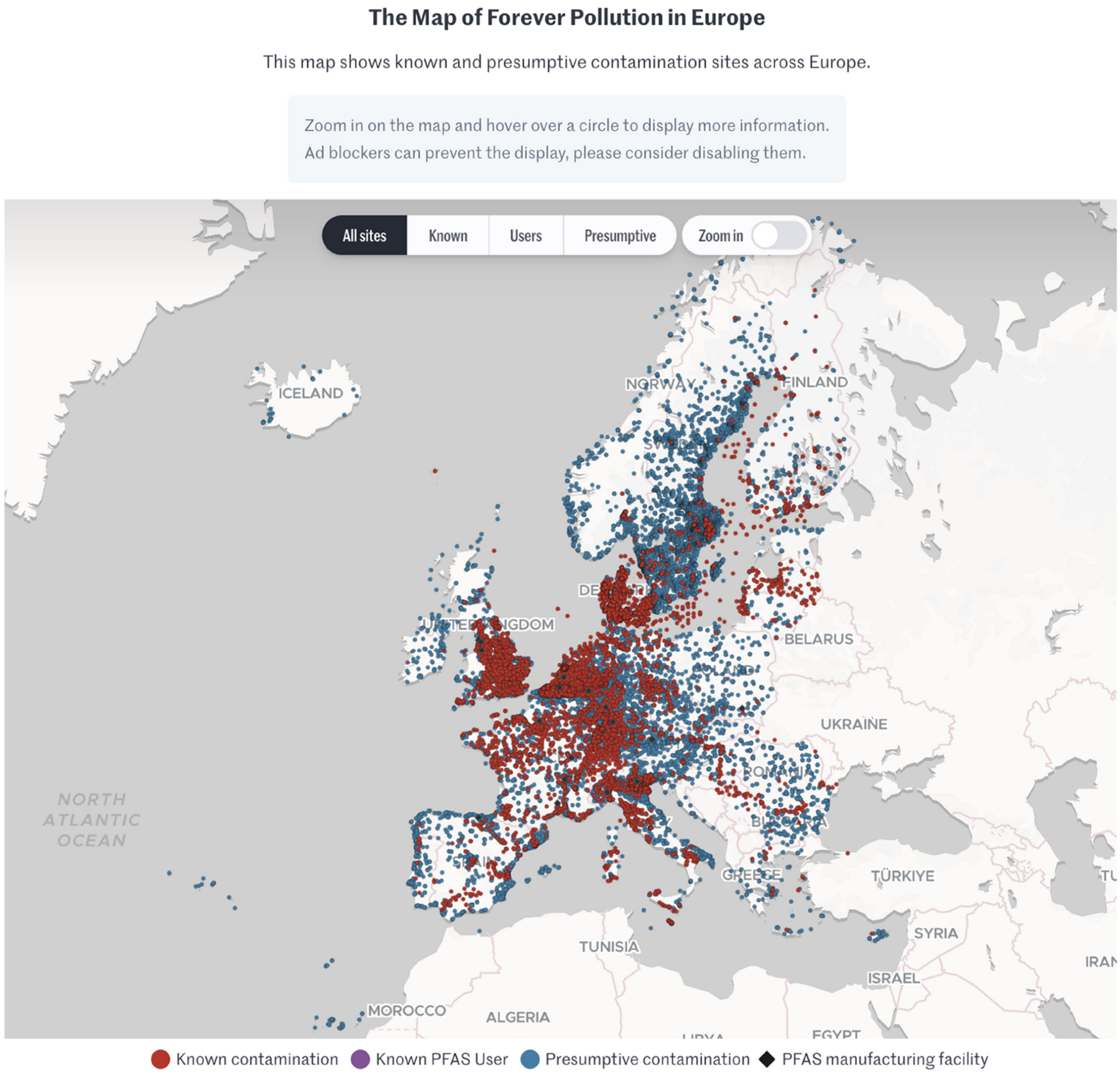

Figure 1. Map of Forever Pollution, August 1, 2023, Le Monde, reproduced with permission, available at https://www.lemonde.fr/en/les-decodeurs/article/2023/02/23/forever-pollution-explore-the-map-of-europe-s-pfas-contamination_6016905_8.html.

acid [PFNA], perfluorobutanesulfonate [PFBS], perfluorohexanoic acid [PFHxA], and perfluorohexanesulfonate [PFHxS]); and how to define a PFAS "hotspot" in the absence of a general definition (defined in the FPP as any location where total PFAS have been measured in any media over 100 ng/L).

Data Analysis and Management. We used Python scripts to analyze data stored in Google Sheets and CSV documents for data gathering, scraping, cleaning, and analysis since the data had many different sources, countries of origin, languages, and units of measurement. We automated the merging and reupload of our datasets via Python. An online interactive map was crafted with vector tiles, which offer a smoother user experience, since we anticipated readers would zoom into very specific locations on the map. The tiles were rendered via Javascript and MapLibre GL JS, and the data symbols were rendered via DeckGL (a WebGL data visualization library). The vector tiles are hosted on MapTiler's servers.

Between February and June 2023, 16 media organizations in 12 countries published over 80 print and online articles, TV stories, and radio or podcast programs.[38] The project dataset including all data shown on the online map is freely downloadable from Le Monde's website.[60] The verified list of known PFAS users and sources is included in Table S-4. An updated, more comprehensive dataset including additional information such as sources and all available PFAS sampling values beyond the six PFAS displayed on the map, is available online, and we recommend using this version of the dataset.[61]

The maps and datasets were last updated in November 2023 to include 335 new known contamination sites in the Walloon Region and Brussels, Belgium. Data about these additional sites were shared by journalists of the Belgian public television RTBF and include previously unpublished values as well as new data the journalists obtained by sampling some locations during an investigation inspired by the FPP.[62]

At this time, no further updates of the map are planned by Le Monde, which lacks the resources to continuously update and maintain it. However, the French National Centre for Scientific Research (CNRS) has been working on refining the data since January 2024 with the goal of improving their usability and convenience to researchers from different disciplines.

■ RESULTS

As of March 1, 2024, 22,934 known contamination sites could be located across 32 European countries (Figure 1 and Table 1), including 11,969 with contamination levels above 100 ng/L.[60] Known contamination sites were identified in all included countries. Known contamination sites were unequally distributed; the seven countries with the most sites had a total of 21,432, while the seven countries with the fewest had a total of 10. Almost half of all sites were located in Belgium and the Netherlands (6791 and 4989, respectively), reflecting extensive national attention to the pollution from the Chemours and 3M facilities in Dordrecht and Zwijndrecht. The known contamination sites include 20 PFAS production facilities in seven countries (Table 2). We could not identify monitoring data for seven of the 20 sites and their surroundings. To our knowledge, the contamination levels near the 3M facility in Zwijndrecht (Belgium) are the highest ever measured globally: 72.8×10^6 ng/L in groundwater for all PFAS (including 48×10^6 ng/L for PFOS and 8×10^6 ng/L for PFOA).[48]

Table 1. Known Contamination Site Statistics Per Country (Not Including 98 Sites in the Sea without Attributed Countries)

country	number of known contamination sites
Austria	41
Belgium	6791
Bulgaria	17
Croatia	5
Cyprus	1
Czech Republic	31
Denmark	2161
Estonia	2
Finland	180
France	1067
Germany	2032
Greece	12
Hungary	25
Ireland	1
Italy	2726
Latvia	111
Lithuania	32
Luxembourg	4
Malta	22
Netherlands	4989
Norway	60
Poland	12
Portugal	9
Romania	21
Serbia	27
Slovakia	17
Slovenia	3
Spain	327
Sweden	222
Switzerland	216
Ukraine	3
United Kingdom	1666
total	22,833

We identified 231 known PFAS users, with 67 located in Germany, 38 in the United Kingdom, and 38 in Italy (Supporting Information Table S-4). Some of those companies also run PFAS manufacturing sites with a record of contamination in Europe and in the United States (Chemours in Mechelen, Belgium; Tefal in Tournus, France; 3M in Kerkrade and Daikin in Oss, both in The Netherlands; Saint-Gobain in Kilrush, Ireland).[63]

Table 2. PFAS Manufacturing Facilities in Europe

name	location	country	active as of 2023	any sampling data available
Dyneon/3M	Gendorf	Germany	yes	yes
Solvay	Bad Wimpfen	Germany	yes	yes
Archroma	Gendorf	Germany	yes	yes
Gore	Gendorf	Germany	yes	yes
Daikin refrigerants	Frankfurt am Main	Germany	yes	no
Lanxess	Leverkusen	Germany	yes	yes
Arkema	Pierre-Bénite	France	yes	yes
Daikin	Pierre-Bénite	France	yes	yes
Solvay	Tavaux	France	yes	no
Solvay	Salindres	France	yes	yes
Chemours	Villers-Saint-Paul	France	yes	yes
Miteni	Trissino	Italy	no	yes
Solvay	Spinetta-Marengo	Italy	yes	yes
AGC	Thornton-Cleveleys	United Kingdom	yes	yes
F2	Preston	United Kingdom	yes	no
Mexichem/Koura	Runcorn	United Kingdom	yes	no
3M	Zwijndrecht	Belgium	yes	yes
Chemours	Dordrecht	Netherlands	yes	yes
Grupa Azoty	Tarnów	Poland	no	no
Arkema	Zaramillo	Spain	no	no

We identified 21,426 presumptive contamination sites across Europe. We identified 13,745 fluorinated AFFF discharge and storage sites. Specifically, we located 641 military sites across Europe, including 321 current and former military air bases and airports, NATO air bases, and army aviation schools. We also identified 978 commercial civilian airports. 1096 firefighting training sites were included, mainly in Flanders (Belgium),[48] Sweden,[47] and Norway,[49] as well as 10,774 firefighting foam incidents in Sweden[47] and 279 in Flanders.[48] We located 2911 industrial facilities, including 1120 paper mills (Table 3).

Table 3. Presumptive Contamination Sites: 2911 Industrial Facilities

industrial activity	sites
manufacture of pulp, paper, and paperboard	1120
treatment and coating of metals	680
manufacture of articles of paper and paperboard	301
manufacture of plastics in primary forms	221
manufacture of refined petroleum products	213
manufacture of other fabricated metal products	132
finishing of textiles	126
manufacture of other organic basic chemicals	45
manufacture of rubber and plastic products	16
tanning and dressing of leather; dressing and dyeing of fur	11
treatment and disposal of hazardous waste	1
not available	45
total	2911

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We identified 4752 sites related to PFAS-containing waste, including 2616 wastewater treatment plants and 1325 landfills for nonhazardous and hazardous waste and incinerators.

■ DISCUSSION

Comprehensive geolocation data are unavailable for multiple types of known PFAS users or presumptive contamination sites, including many industrial activities, fire training facilities, and firefighting foam incidents. The number of sites identified in each country or area reflects the amount of testing conducted by the authorities or scientists and not just the extent of PFAS contamination. Because levels of actual contamination cannot be understood apart from the extent of testing, the true magnitude of PFAS contamination remains unknown and may be underestimated. Some sites with measurable PFAS levels have no identified source of pollution, and the contamination could come from a single point source, from multiple sources, or, for sites with lower levels of PFAS, possibly diffuse contamination. The presumptive PFAS contamination model also omits some facilities that are sources of contamination while likely including some sites without contamination.[18] Identifying specific sources or sites from which the contamination originated was beyond the scope of this project. Differentiating sites based on local contamination sources versus nonpoint-source emissions or based on the magnitude of environmental contamination would be valuable for regulatory decision-making and is a needed area of research.

Some countries or areas appear to have many contamination sites due to comprehensive monitoring efforts to identify and address contamination. Conversely, countries or areas that have no or few known sources of contamination have likely done less testing and, thus, are unaware of other contamination sites. For example, it appears that Denmark is extensively contaminated, while Germany has very few known contamination sites, but this reflects extensive testing conducted by the Danish regional authorities. Although the German state (Bundesland) authorities released some data through press and FOI requests, we suspect that additional data exist. Some sites may have incomplete or missing data due to a lack of publicly available information. For example, the local authorities in Germany and private drinking water suppliers in other countries keep sampling data unpublished or confidential. As the E-PRTR contains emission data for only the largest industrial complexes in Europe, thousands of smaller facilities were unable to be geolocated and did not appear on the map. As one known example of existing but not publicly available sampling data, private water operators are preparing the application of the Drinking Water Directive by January 2026 by sampling numerous locations, but none of these data are included in the FPP because they are treated as confidential by the operators.

In multiple ways, the FPP made public and transparent data that previously had existed as unseen science, knowledge that is produced but never shared beyond institutional boundaries.[64] This included government sampling data that had never been made public, as well as data intentionally hidden by some authorities. For example, some previously confidential sampling data were obtained through press and FOI requests in France, Germany, and Scotland, as well as at the EU level. Despite the Aarhus Convention, which guarantees access to information in environmental matters,[65] the EU Commission also denied one FOI request on a pilot study on PFAS to develop a Ground Water Watch List (GWWL),[66] refusing to share the data sets of the 11 participating countries (Belgium, Switzerland, Czech Republic, France, Italy, the Netherlands, Austria, Germany, Sweden, Finland, and the United Kingdom) whose groundwaters all contained detectable levels of PFAS. In its final decision regarding our "confirmatory application", the Secretariat General of the Commission stated that the data "is not in the possession of the Commission nor stored on any of its servers since it was an external contractor who was responsible for collecting and analyzing it.[67] The Commission received only the anonymized version of the documents which it then published on the CIRCABC platform", the repository of public documents from all EU institutions, agencies, and bodies. Citing Article 2(3) of Regulation (EC) No 1049/2001 regarding public access to European Parliament, Council and Commission documents,[68] the Commission further argued that "the right of access as defined in that regulation applies only to existing documents in the possession of the institution. Given that the European Commission does not hold any such documents corresponding to the description given in your application, it is not in a position to fulfil your request". In addition, the Commission argued that the contractor was "only responsible for collecting and analyzing the data", described as "purely technical tasks, severable from the public functions exercised by the Commission", that "cannot be considered as having public responsibilities or functions or providing public services, relating to the environment".[68] Consequently, Article 7 of Regulation 1367/2006, which obliges an EU institution receiving a request for access to environmental information detained by another body to inform the relevant body or transfer the request "as promptly as possible" was, according to the Commission, not applicable.

In one instance, a report investigating a contaminated area in Greece, commissioned in 2017 by the Region of Attica to a scientific team of the public University of Athens and covered by a nondisclosure agreement, was leaked by a source to our Greek media partner Reporters United. It revealed the first hotspot located in Greece, with PFAS concentrations in the Asopos River near an industrial park reaching an average of 321 ng/L for 8 PFAS.[69]

Finally, we corrected the dataset as needed after the initial publication of the FPP in February 2023. Most errors were due to the poor data quality of submitted data in the E-PRTR, such as faulty and imprecise geolocation data, misclassification of the industrial activity, or outdated company names. Rigorous data quality checks at the member state level before submission to the E-PRTR could resolve those problems in the future.

The presumptive contamination approach is valuable because it allows governments and remediation initiatives to prioritize sampling campaigns and tailor action plans to protect the public. Several states in the US,[18] the French environmental authorities,[70] and the EU Commission have used similar approaches to identify sampling targets for PFAS contamination based on facility type. In October 2022, the EU Commission listed nine industrial activities "where PFAS are likely used (textiles, leather, carpets, paper, paints and varnishes, cleaning products, metal treatments, car washes, plastic/resins/rubber)"[71] based on NACE codes.[52] In France, the Bureau de Recherches Géologiques et Minières (BRGM) has listed 117 NAF (nomenclature d'activités française) codes corresponding to industrial activities correlated to PFAS use in the ActiviPoll database.[72] In June 2023, ActiviPoll was used by the French government to establish a list of approximately

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5000 industrial facilities ordered to test for the presence of PFAS in their aqueous discharges. In Belgium, Bruxelles Environnement, the administration for the Environment and Energy of the Brussels-Capital Region, built an online map of suspected PFAS contamination using a similar reasoning.[73] In Germany, the German Environment Agency, UBA, took a similar approach to match environmental trifluoroacetic acid (TFA) contamination with emissions sources, using the list of companies with a TFA registration at the ECHA.[74] These data are not included in the FPP data set. Each European country has its own nomenclature for its economic activities. A great number of additional presumptive contamination sites may be geolocated by cross-utilizing resources available in each country, but this was beyond the scope of the FPP. Additionally, the number of identified known PFAS users is likely an underestimation due to resource limitations and data gaps. These sites are particularly deserving of additional identification, PFAS sampling, and possible regulatory action.

Applications and Lessons Learned. The detailed strategies and tactics of the "expert-reviewed journalism" behind the FPP, including the scale of the multinational and multiinstitutional collaboration, the broad use of press and FOI requests, detailed dataset analysis, and collaboration with scientific advisors, are specific to this project. However, environmental health journalism has a long history of supporting transparency and the use of data to advance regulatory, advocacy, and public health efforts. As early as in the 1920s, the press played a pivotal role in reporting workers' deaths and illnesses in the first facilities manufacturing tetraethyl lead for gasoline.[75] Rachel Carson's landmark *Silent Spring*, which raised broad awareness about the consequences of pesticide use on health and the environment, was first published not as a book but as a *New Yorker* series in June 1962.[76] Widely influential investigations of the asbestos industry[77] and endocrine disruption[78] similarly involved journalists coauthoring or working closely with scientists to ensure both rigorous analysis and public appeal. The *Chicago Tribune's* 2012 groundbreaking investigative journalism series, "Playing with Fire", was highly effective in calling attention to the hazards of organohalogen flame retardant chemicals, spurring national attention and supporting the first statutory reform of industrial chemicals management in the United States since the 1970s.[79,80]

Regarding PFAS specifically, journalists have played important roles as early as 2007, when Callie Lyons' *Stain-resistant, nonstick, waterproof, and lethal: The hidden dangers of C8* told the story of PFOA contamination at DuPont's Parkersburg, West Virginia plant.[81] A decade later, Vaughn Hagerty with the Wilmington Star News broke the story of one of the nation's largest contamination crises resulting from Chemours, the DuPont spinoff, releasing PFAS derived from their GenX replacement production technology, such as hexafluoropropylene oxide dimer acid and its ammonium salt (HPFO−DA), into the Cape Fear River in eastern North Carolina.[82] Investigative journalist Sharon Lerner published numerous in-depth stories on PFAS with *The Intercept*, particularly examining the regulatory-industry nexus.[83] In all these examples, the investigative journalists have demonstrated scientific knowledge that both synthesizes the scholarly literature and also looks into the social, legal, and activist origins of the discovery of health hazards.

The FPP was a unique and innovative cross-border and cross-field project in several ways, including the international scale, the multidisciplinary "expert-reviewers" group, the considerable amount of generated data, and the scaling-up from five to 30 journalists. It has raised major interest and discussions in journalism circles about how to work effectively with scientists. From our experience, such efforts require a trustful and mutually beneficial relationship based on the following principles: (1) before anything else, journalists have to reach a high level of expertise about the topic and a good knowledge of the scientific ecosystem and customs to avoid wasting time, misunderstandings, and errors; (2) clearly stated boundaries regarding published outputs; (3) the experts' contributions have to be recognized in any final products; and (4) both parties should benefit from each discipline's methodologies, such as press requests and FOI material collected by journalists and OSINT methods. For research scientists in particular, this type of collaboration offers advantages including the opportunity to work with original data, broad impact, improvement of scientific literacy in the public, and the ability of research to contribute to meaningful change.[84]

Regulatory and Public Impacts. The FPP's primary goals were to inform the public by providing a tool for impacted community members, researchers, and regulators and to contribute to building knowledge on PFAS contamination for the public interest. As of March 2024, a year after release, the publicly available datasets are being used in at least a dozen research projects, including a published spatial prediction of PFAS levels in EU soils[85] and research through the European Commission-funded project ARAGORN (Achieving Remediation And GOverning Restoration of contaminated soils Now).[86] Major regulatory and scientific circles have solicited members of the FPP to present our methodology in order to use it as a basis to investigate or remediate pollution in their areas, including Conferences of the Parties to the Basel, Rotterdam, and Stockholm Conventions; the Food and Agriculture Organization (FAO) of the United Nations; the European Commission; the Belgian presidency of the EU; and the Organisation for Economic Co-operation and Development (OECD). In France, our investigation was used to sustain several criminal prosecutions and legal proceedings. Finally, members of the FPP have received personal communications from many players in the European regulatory world that the project has significantly raised the profile of PFAS contamination in the EU, convincing high-level officials and political actors of the gravity of the contamination. For example, Valentina Bertato, Policy Officer at the Directorate General for the Environment of the EU Commission, declared publicly that "when we were working on the [EU] Chemicals Strategy for Sustainability, we [the EU Commission] would have really liked to have this data because I think we could have had an even more compelling case of action on chemicals".[87]

The FPP has already had observable regulatory impacts, as well. The "Known PFAS users" data set has been integrated into wider work on PFAS contamination by the UK Environment Agency. Other regulators could match the known users list with high PFAS concentrations detected in the environment in order to quickly identify probable contamination sources. For example, 29,000 ng/L of PFOS + PFOA were detected in groundwater near the Chemours facility in Mechelen, Belgium.[60] The FPP shows that "expert-reviewed journalism" can contribute not just to public or regulatory efforts but also to scientific fields because journalists

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have expertise and networks able to uncover and make public data sources otherwise hidden from view.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge at https://pubs.acs.org/doi/10.1021/acs.est.3c09746.

Tables explaining how industrial facilities were identified using NACE codes; Table S-1 connects NAICS codes (US) to NACE codes (EU); Table S-2 connects NACE codes to the E-PRTR activity labels (EU); and Table S-3 lists the final 29 NACE codes used in the FPP; Table S-4 includes the full list of Known PFAS Users included in the FPP (PDF)

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Notes

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