



## 6 Media-Specific Occurrence

The long period of time during which PFAS have been produced and the many sources of PFAS release to the environment have resulted in low-level contamination of most environmental media worldwide. The concentrations of these human-caused ambient or “background” concentrations may vary widely, based on proximity to industrial areas, patterns of air and water dispersion, and many other factors. As a result, any claims regarding “universal” values for background levels of PFAS should be viewed skeptically. This section provides a relative understanding of PFAS concentrations in various environmental media but does not represent an exhaustive literature review. Note that media-specific occurrences of PFAS are constantly being added in the literature and on state, federal, and other countries’ PFAS websites.

The following sections include figures summarizing the observed concentrations of PFAS that have been reported in the literature. Important details concerning each study used in developing the figures are included in the tables in [Section 17.1](#). As discussed under PFAS Releases to the Environment ([Section 2.6](#)), the presence of PFAS in environmental media and ecological receptors has been traced to air emissions; direct discharges to soil, groundwater, and surface water; and leakage from landfills. Sections on Phase Partitioning ([Section 5.2](#)) and Media-Specific Migration Processes ([Section 5.3](#)) illustrate that PFAS occurrence in the air, aqueous, and solid phases is highly interrelated. Subsequent sections on Human Health Effects ([Section 7.1](#)) and Ecological Toxicology ([Section 7.2](#)) suggest that PFAS risks to human health may result from exposure via drinking water, groundwater, soils, food, and other media types. Further, ecological impacts are observed on a global scale. This suggests that a complete assessment of PFAS sources and exposure risks, including fate and transport processes that may drive future exposure concerns, requires understanding of PFAS occurrence across multiple phases. This section focuses on occurrence in air, soil and sediment, groundwater, surface water, and biota.

PFAS occurrence in several media types is an active area of research. As discussed in [Section 11](#), sampling and analytical methods are still being optimized and standardized; thus, it is difficult to compare results between studies and conclusions may change over time. PFAS concentrations presented below for different media often indicate maximum values; mean or median values are often well below the maximum values reported for different studies. The processes that influence media-specific PFAS concentrations are illustrated in CSMs shown in [Figure 2-18](#), [Figure 2-19](#) and [Figure 2-20](#).

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6.1	<a href="#">Air</a>
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6.3	<a href="#">Groundwater</a>
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6.5	<a href="#">Biota</a>

### 6.1 Air

Certain PFAS are found in ambient air, with elevated concentrations observed or expected in urban areas nearest to emission sources described in [Section 2.6](#). These include industrial facilities that produce PFAS or use PFAS or products in manufacturing; areas where Class B firefighting foams containing fluorine are used or released; waste management facilities, including landfills and wastewater treatment plants; and areas of biosolids production and application ([Borthakur et al. 2022](#); [Barton et al. 2006](#); [Ahrens et al. 2011](#); [Liu et al. 2015](#)). Reported concentrations for ionic species such as PFOA and PFOS typically fall within a range of about 1–20 pg/m<sup>3</sup> (picograms/cubic meter), although concentrations of PFOA as high as 900,000 pg/m<sup>3</sup> have been observed near large manufacturing facilities, including in Parkersburg, West Virginia ([Barton et al. 2006](#)). Concentrations of volatile PFAS such as FTOHs can be in the hundreds of pg/m<sup>3</sup> in outdoor air ([Figure 6-1A](#) and [Table 17-1A](#)). Atmospheric transport and deposition of PFAS occur on regional and global scales suggesting that low level

concentrations detected in soil or other media are not necessarily indicative of a local source (Table 17-2 and Section 5.3.2).

PFAS have also been observed in indoor air and dust in homes, offices, and other indoor environments (Figure 6-1B and Table 17-1B). Indoor air concentrations of certain PFAS can be higher than outdoor air concentrations due to the presence of indoor sources (Fromme et al. 2015; Fraser et al. 2012; Goosey and Harrad 2012; Shoeib et al. 2011; Kaiser et al. 2010; Langer, Dreyer, and Ebinghaus 2010; Strynar and Lindstrom 2008; Shoeib et al. 2004). Examples of indoor sources of potential PFAS exposure include stain- and water-resistant coatings used on a number of consumer products, such as carpets, upholstery, clothing, grease-resistant paper, food packaging, and nonstick cookware and ingredients in cleaning products, personal care products, cosmetics, paints, varnishes, and sealants (ATSDR 2019; Liu et al. 2015; Liu et al. 2014; Gewurtz et al. 2009; Guo et al. 2009). PFAS concentrations in indoor air have been reported in the range of about 1-440  $\text{pg}/\text{m}^3$  for PFOA and PFOS. Concentrations of volatile PFAS such as FTOHs have been reported on the order of 10,000-50,000  $\text{pg}/\text{m}^3$  in schools, homes, and offices. Concentrations of FTOHs have been observed in excess of 300,000  $\text{pg}/\text{m}^3$  inside commercial buildings (Fromme et al. 2010).

As discussed in Section 5.3.2, short-range atmospheric transport and deposition may result in PFAS contamination in terrestrial and aquatic systems near points of significant emissions, contaminating soil, groundwater, and other media of concern (Davis et al. 2007), as well as several miles from industrial emission sources (Shin et al. 2011; Post, Cohn, and Cooper 2012; NYS DOH 2016; NH DES 2017; VT DEC 2016). Releases of ionic PFAS from factories are likely tied to particulate matter (Barton et al. 2006), which settle to the ground in dry weather and are also wet-scavenged by precipitation as discussed in Section 5.3.2. Models indicate that deposition depends on amount of PFAS emissions, local topography, particle size, weather patterns, and release characteristics such as smokestack height, effluent flow rate, and effluent temperature. In addition to short-range transport and deposition, long-range transport processes are responsible for a wide distribution of PFAS across the earth, as evidenced by their occurrence in biota and environmental media in remote regions as far as the Arctic and Antarctic. Long-range transport processes and effects are similar to atmospheric transport of other recalcitrant contaminants.

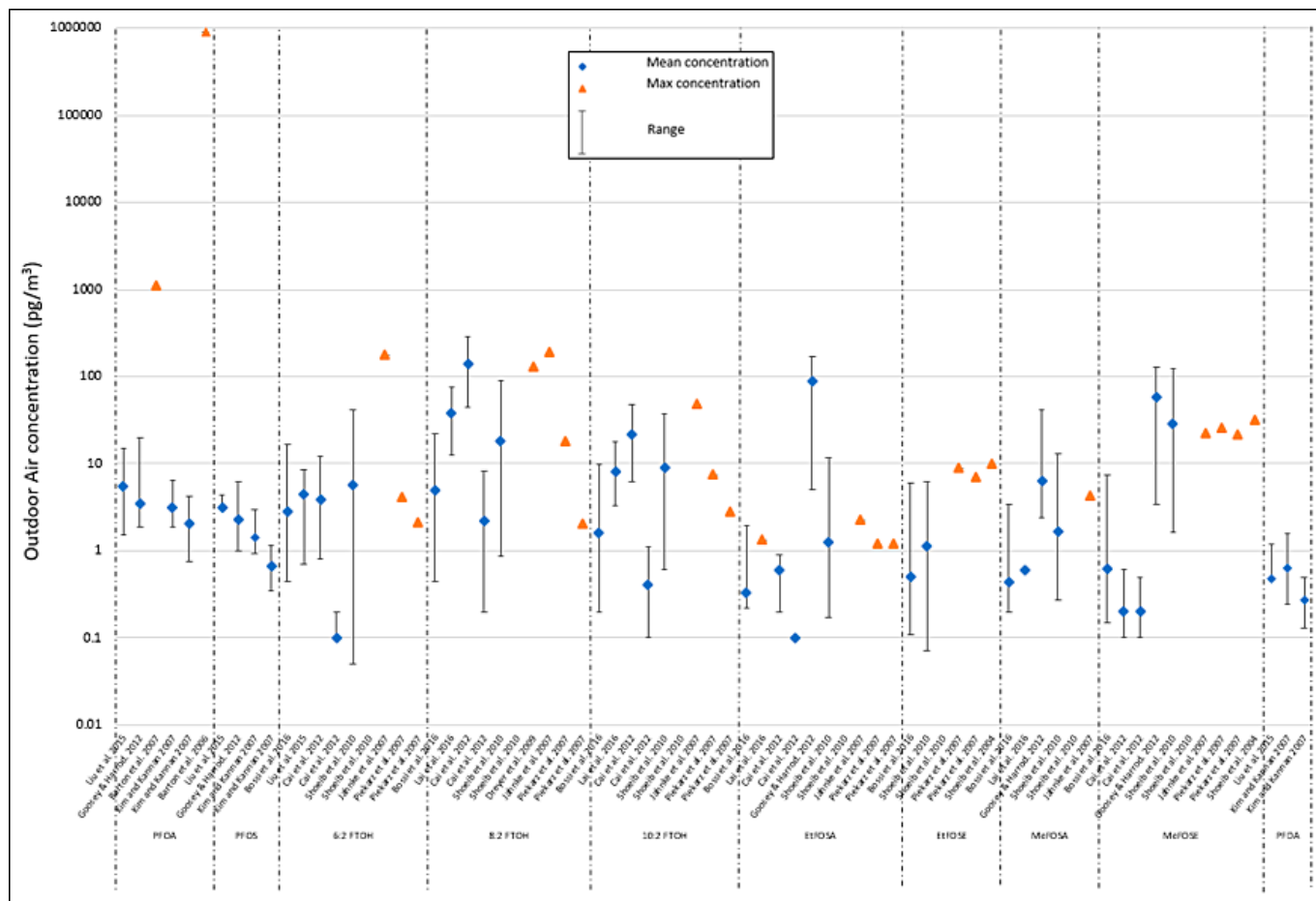
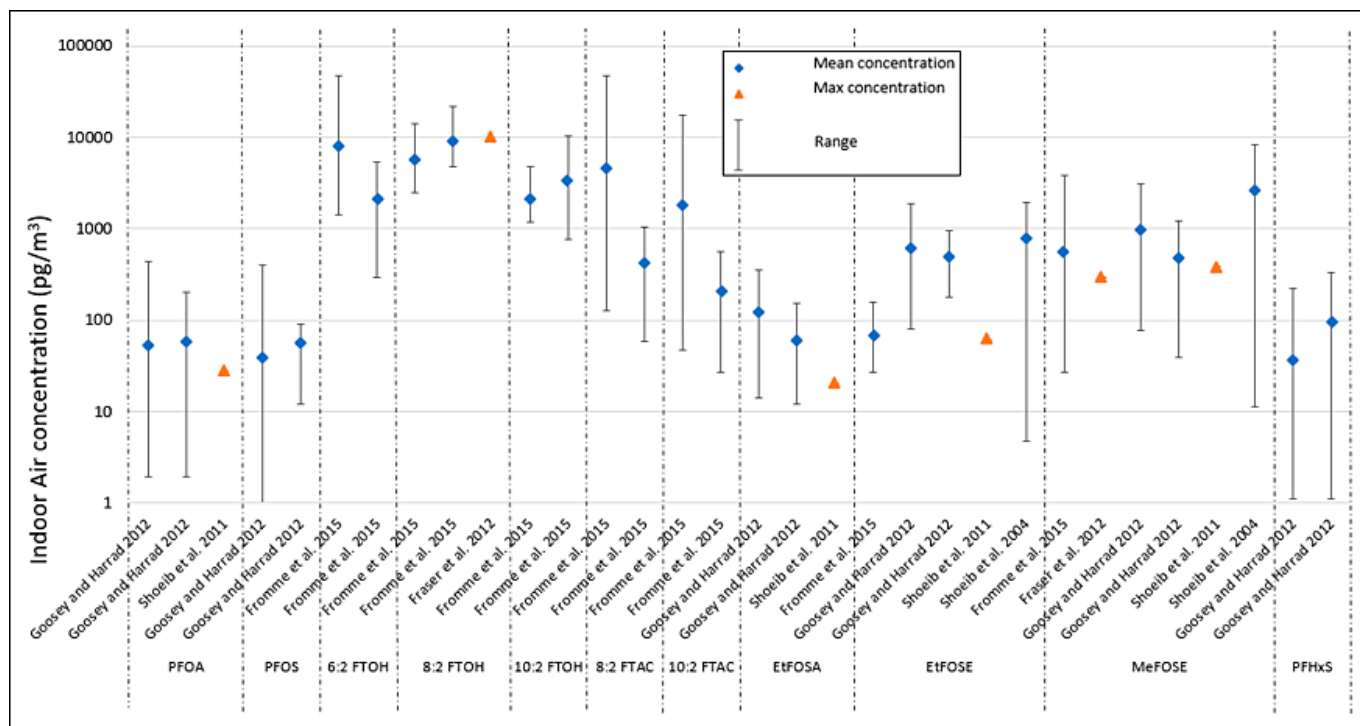


Figure 6-1A. Observed PFAS concentrations in outdoor air.



**Figure 6-1B. Observed PFAS concentrations in indoor air.**

## 6.2 Soil and Sediment

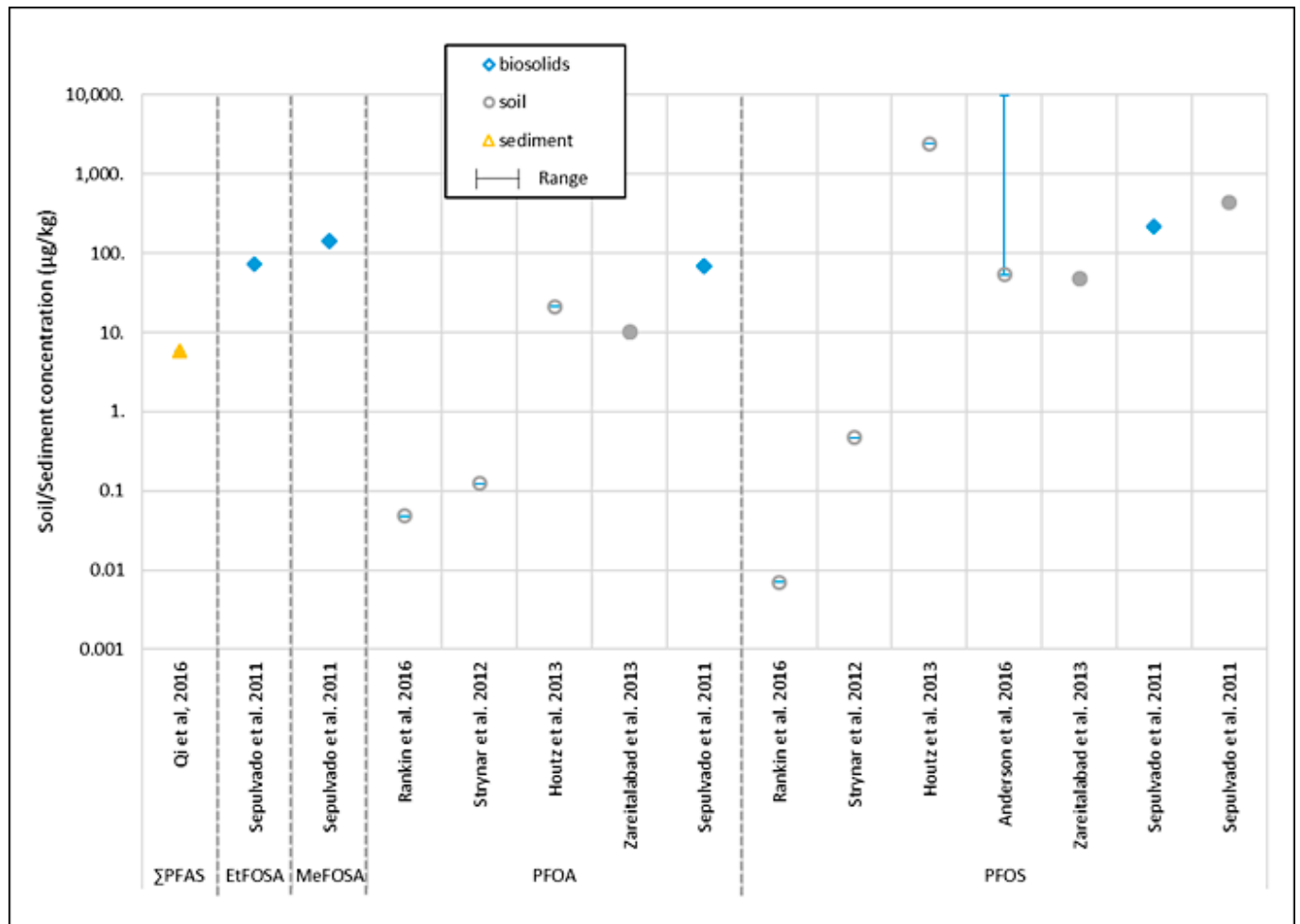
PFAS occurrence in soil and sediment can result from direct deposition (for example, AFFF or industrial discharge), or indirectly through exposure to impacted media (for example, atmospheric deposition, landfill leachate, application of biosolids) (Figure 6-2 and Table 17-2). See Sections 2.6.4.2 and 5.3.3. As a result of these depositions, soil and sediment may act as secondary sources of PFAS via leaching to groundwater and runoff to surface water through leaching and percolation processes, respectively. The concentration and distribution of PFAS observed in soils and sediments is complex and can be a function of source (direct or indirect), site-specific considerations (for example, TOC, particle surface charges, and phase interfaces, see Section 5.2.3) and PFAS-specific chemistry (for example, alkyl chain length and ionic functional group). PFOS, PFOA, and other long-chain PFAAs are typically the predominant PFAS detected in surface soils and sediments (Zhu et al. 2019; Rankin et al. 2016; Strynar et al. 2012; Cai et al. 2022).

PFAA concentrations in soil have been observed across a wide range of locations, which suggests that detection of a PFAA in soil does not always imply a local source, and may indicate atmospheric transport and deposition (Table 17-2 and Section 5.3.2).

Individual PFAS concentrations may be above 1,000  $\mu\text{g}/\text{kg}$  at AFFF sites. In comparison to AFFF sites, published data on soil PFAS concentrations in industrial settings are limited (Table 17-2). PFAS soil concentrations at industrial sites may be highly variable, depending on the nature of PFAS release and proximity to the source. Concentrations at sites with applied biosolids or sludge will vary depending upon application rates, frequency, duration, and concentration of PFAS in the applied material.

PFAS discharge to surface waters has also affected sediments. Information about PFAS occurrence in surface water is included in Section 6.4 and Table 17-4. Detected concentrations for surface sediments in lakes and rivers reported in the literature generally range up to approximately 100  $\mu\text{g}/\text{kg}$ , and concentrations and relative distributions of PFAS are variable depending upon types of sources and distance from point sources (Table 17-2). At least one study showed that PFAS concentrations correlate to parameters such as TOC, nitrogen, and phosphorus in sediment (Qi et al. 2016). Dated sediment cores have been used to evaluate deposition of lead, mercury, and other contaminants through time. A recent study of Great Lakes cores (Codling et al. 2018) suggested that the same techniques will also be applicable to PFAS deposition trends. Reported values for the sum of PFAS in cores ranged from nondetect to 46.6  $\mu\text{g}/\text{kg}$ , and concentrations typically increase with time in the cores. Sediment core analysis may be effective for estimating deposition rates only for a subset of PFAS. Long-chain PFAS exhibit greater sorption to sediment, with concentration at a given depth interval representing deposition during that time period. Short-chain PFAAs showed less sorption and were more mobile in the sediment column, and

therefore were not effective indicators of PFAS deposition rates. This suggests that as more short-chain PFAS are used as replacements for PFAS applications, sediment cores will have less utility for evaluating trends in deposition rates.



**Figure 6-2. Observed PFAS concentrations in soils and sediment.**

### 6.3 Groundwater

USEPA has assembled an extensive data set of the occurrence of six PFAAs in public drinking water. This data set is the result of required monitoring of approximately 4,900 public water systems (all large systems serving more than 10,000 people, plus a subset of smaller systems) for six PFAAs in finished drinking water at points of entry to the drinking water distribution system. The study was conducted between 2013 and 2015 under the third Unregulated Contaminant Monitoring Rule (UCMR3) and included the results from treated water that originated from groundwater wells (n = 22,624), surface water (n = 12,733), and mixed sources (n = 792) (USEPA 2017). A summary of the UCMR3 occurrence data, including analytical reports, is included in Section 8.2.2.2. One or more PFAAs were detected in 4% of the reporting public water systems (USEPA 2017); however, groundwater sources had approximately double the detection rate of surface water sources (Hu et al. 2016). In addition, 59 out of 4,905 public water systems (PWSs) reported PFOA and PFOS at concentrations that exceeded the 2016 USEPA health advisory of 0.07 µg/L (ATSDR 2018); these systems represent 1.3% of all of the PWSs that monitored under UCMR3. Detections were geographically widespread but showed quantifiable associations with suspected sources, including industrial sites, military fire training areas, AFFF-certified airports, and wastewater treatment facilities (Hu et al. 2016). Individual states are collecting information on PFAS occurrence in smaller public water supplies such as schools and mobile home parks that do not meet the threshold to comply with the Unregulated Contaminant Monitoring Rule, so were not sampled during UCMR3, and for which data are often publicly available, for example, in New Hampshire at NH DES (2020).

Groundwater occurrence data collected as part of domestic and international studies have also characterized the range of PFAS concentrations associated with AFFF release sites, industrial facilities, and landfills; examples of these study results are provided in Figure 6-3 and Table 17-3.

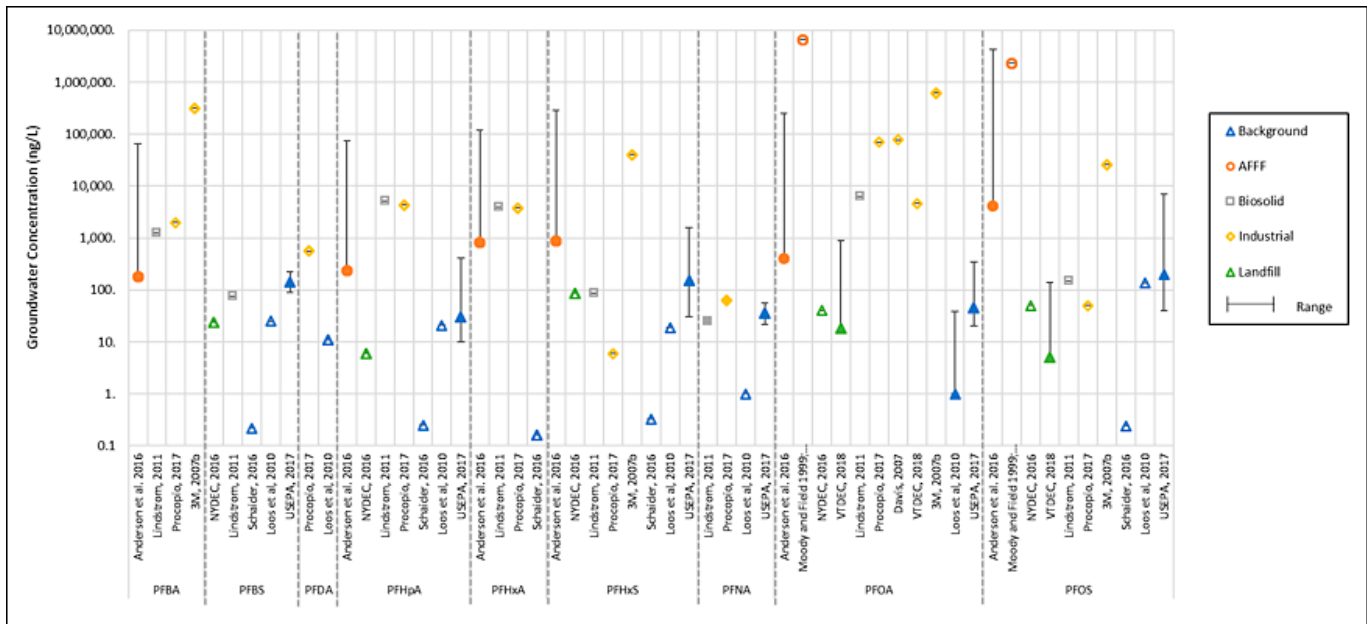
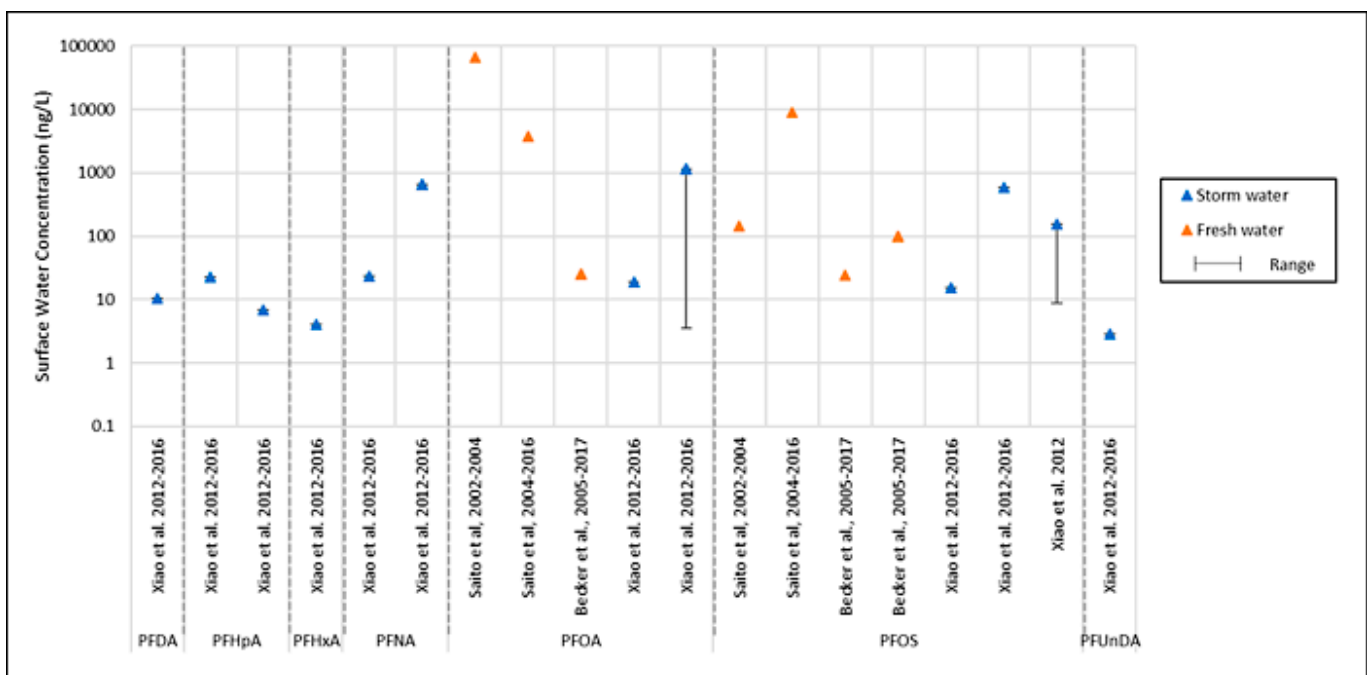


Figure 6-3. Observed PFAS concentrations in groundwater.

## 6.4 Surface Water

Freshwater, marine water, and stormwater PFAS concentrations usually depend on proximity to the point of release and source concentrations. In addition to releases associated with identified sources, stormwater runoff from nonpoint sources may contribute significant loads of PFAS to surface water (Wilkinson et al. 2017; Zushi and Masunaga 2009). The sorption of PFAS to suspended solids may affect surface water PFAS concentrations. Suspended microplastics may also influence PFAS in surface water (Llorca et al. 2018). Figure 6-4 and Table 17-4 present examples of observed PFOS and PFOA surface water concentrations, organized by source type. In addition to PFOS and PFOA, many other PFAS have been observed in surface waters, including compounds other than PFAAs. For example, a recent study found perfluoro-2-propoxypropanoic acid (PFPrOPra also known as the GenX chemical HFPO-DA) in untreated water drawn from the Cape Fear River in North Carolina at concentrations up to 560 ng/L, and GenX was just one of many non-alkyl acid PFAS identified (Sun et al. 2016). Surface water occurrence is also an important source of drinking water supply impacts (USEPA 2018; Post et al. 2013). Information about surface water quality is included in Section 16 and occurrences in Table 17-4.



**Figure 6-4. Observed PFAS concentrations in surface water.**

## 6.5 Biota

Because PFAS are distributed globally and have a propensity to bioconcentrate, they have been found in fish, wildlife, and humans. PFAAs, particularly PFOS, are typically the dominant PFAS detected in biota ([Houde et al. 2011](#)). PFAA concentrations in biota are influenced by uptake and elimination of both PFAAs and their precursors, as well as biotransformation rates of PFAA precursors ([Asher et al. 2012](#); [Gebbinck, Bignert, and Berger 2016](#)). Therefore, concentrations of PFAAs observed in biota at one location may not reflect concentrations in other environmental media.

### 6.5.1 Plants

Studies show evidence of uptake and accumulation of PFAAs by plants in several settings and applications, including both controlled experiments and field investigations. Concerns about introducing PFAAs into livestock or crops have led to investigations of uptake and accumulation in plants ([Section 5.6](#)). Uptake mechanisms and the extent to which native plant species remove and accumulate PFAS have not been as well studied.

PFAS may be introduced to plants from soil, water, or air by:

- irrigation water
- the application of biosolids or sludge-amended soils
- soil and groundwater at PFAS sites or near releases of PFAS
- exposure through contact with rainwater and atmospheric deposition

Studies demonstrating plant uptake of PFAAs have focused on irrigated crops ([Stahl et al. 2009](#); [Scher et al. 2018](#); [Bolan et al. 2021](#)), crops in biosolids-amended soil ([Yoo et al. 2011](#); [Blaine et al. 2013](#); [Blaine et al. 2014](#); [Felizeter et al. 2021](#); [Costello and Lee 2020](#); [Knight et al. 2021](#)), and aquatic plants in constructed wetlands ([Chen, Lo, and Lee 2012](#)). Other investigations have focused on flora exposed to PFAAs in the natural environment ([Zhang et al. 2015](#)) or near known PFAS sources ([Shan et al. 2014](#)). Based on bioconcentration factors discussed in [Section 5.6](#), concentrations in plants will generally reflect the same concentrations in soil and, for trees with deep roots, groundwater ([Gobelius, Lewis, and Ahrens 2017](#)).

### 6.5.2 Invertebrates

Invertebrates act as the main component of the food web base and play a key role in the dynamics of biomagnification. Aquatic invertebrates can reside in the water column, as well as on (or in) the sediment substrate. In higher trophic level organisms, PFOS has been documented as the dominant PFAS, with concentrations increasing up the food chain, while PFOA has a lower bioaccumulation potential with similar concentrations among species of different trophic level animals ([Houde et al. 2011](#); [Conder et al. 2008](#)). In invertebrates, both PFOS and PFOA have maximum values within similar ranges ([Ahrens and Bundshuh 2014](#)). Studies present a PFAS range of approximately 0.1–10 mg/kg in invertebrate tissue, although their sources predominantly address marine organisms ([Houde et al. 2011](#)). Similar levels of PFOS have been found in freshwater invertebrates (< 2–4.3 mg/kg) with a BCF (biota/water) estimated at 1,000 L/kg ([Kannan et al. 2005](#)). Concentrations of PFOS, PFCAs, and heptadecafluorooctane sulfonamide (PFOSA) have been observed in Lake Ontario invertebrates, ranging from < 0.5 to 280 mg/kg ([Martin et al. 2004](#)). The PFAS concentrations in invertebrates were greater than in fish from this lake.

In soil invertebrates, current research indicates that bioaccumulation potential of PFOS is low, as is biomagnification (increasing concentrations in predators over their prey) from lower to higher trophic level organisms ([CEPA 2017](#)). In biosolids-amended soils, the mean PFAS BAFs in earthworms have been found to range from 2.2 (PFOA) to 198 (PFDoA) g dry weight (dw) soil/g dw worm ([Navarro et al. 2016](#)). Maximum BAFs in earthworms for all PFAS types have been observed at <45 g dw soil/g dw worm for biosolids-amended soils and <140 g dw soil/g dw worm for soils contaminated with AFFF ([Rich et al. 2015](#)).

### 6.5.3 Fish

Accumulation of PFAS in fish is well documented, particularly for PFOS, longer chained PFCAs (with eight or more carbons), and perfluorodecane sulfonate (PFDS) ([Houde et al. 2011](#); [Martin et al. 2013](#); [Conder et al. 2008](#)). PFOS generally has the highest concentrations in fish due to the historically high use of this chemical and its bioaccumulation potential ([Houde et al. 2011](#)). PFDS, long-chain PFCAs, and other PFAS have also been measured in fish ([Houde et al. 2011](#); [Fakouri Baygi et al.](#)

2016).

In fish, PFOS tends to partition to tissues of high protein density, including the liver, blood serum, and kidney (Falk et al. 2015; Ng and Hungerbühler 2013). This distribution pattern is contrary to other persistent chemicals, which tend to partition to adipose tissue. Concentrations of PFOS and other PFAAs tend to be higher in whole fish samples compared with fillets given that a major fraction of PFAAs is found in the carcasses of fish rather than fillets (Fliedner et al. 2018). PFAA concentrations sometimes increase with fish size; however, the relationship with fish size is not consistent as observed for other contaminants such as mercury (Babut et al. 2017; Gewurtz et al. 2014).

Fish data for PFOS collected near known sources (for example, AFFF sites) from some key studies are summarized in Figure 6-5 and Table 17-5.

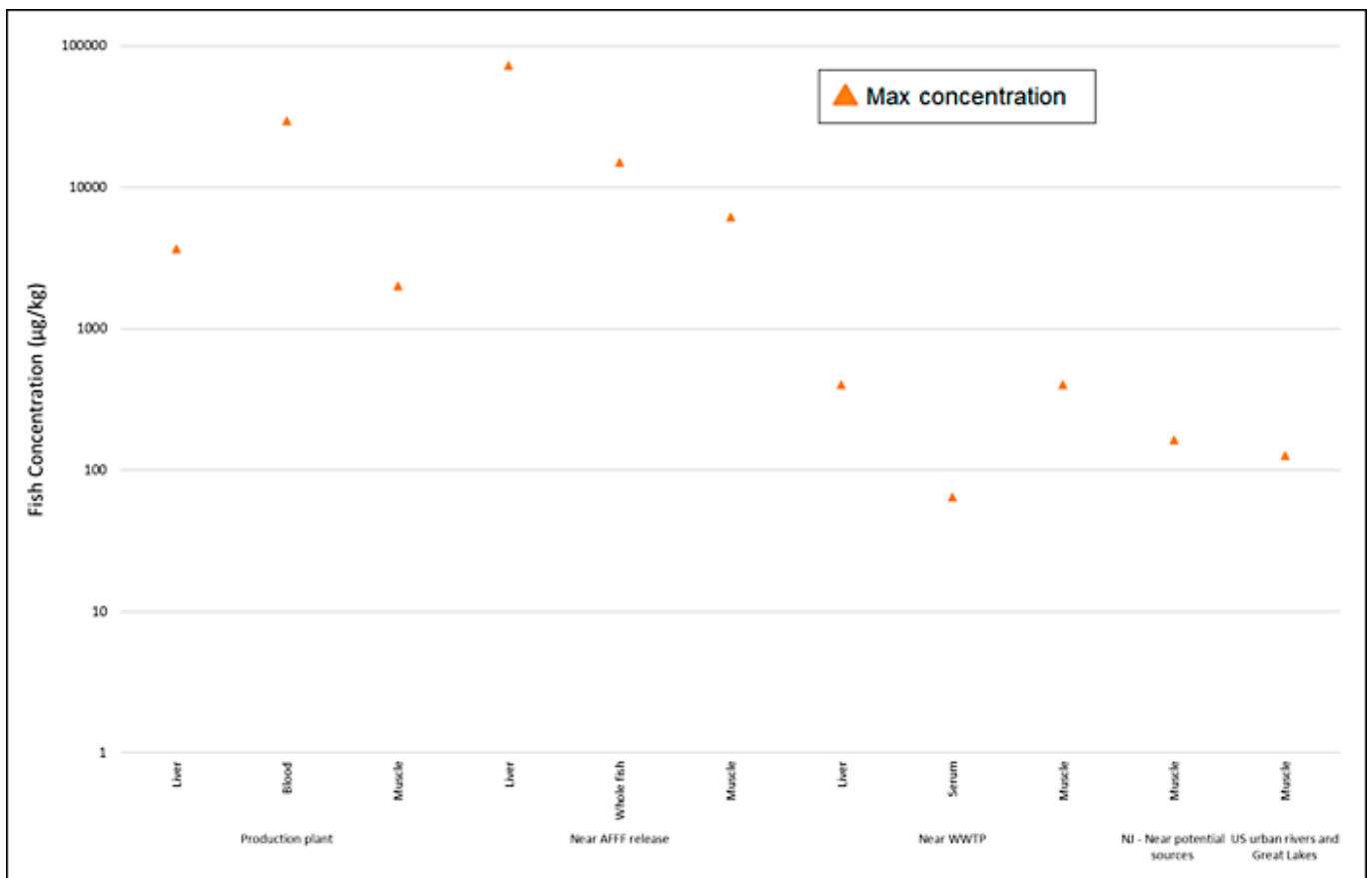


Figure 6-5. Observed PFAS concentrations in fish.

### 6.5.4 Vertebrates

Most research addressing PFAS concentrations in vertebrates focuses on temporal trends in animals at the top of the food chain, such as piscivorous birds (for example, seagulls) and mammals (for example, dolphins, seals). The concentrations are often reported in protein-rich organs known to concentrate PFAS. For example, to evaluate temporal trends between 2002 and 2014, levels of PFAS were measured in liver samples of Indo-Pacific humpback dolphins and finless porpoises (136–15,300 and 30.5–2,720 ng/g dw, respectively) (Gui et al. 2019). Livers of Beluga whales in the Arctic were the only organ sampled to better understand the relative bioaccumulation of persistent organic compounds (Reiner et al. 2011). These data using top marine predators as “sentinels” of PFAS are important in terms of assessing whether concentration trends are increasing or decreasing in the global environment.

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