PFBS in the Environment:
Monitoring and Physical-Chemical Data Related to the Environmental Distribution of Perfluorobutanesulfonic Acid

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Executive Summary

The Norwegian Environment Agency is currently considering whether the substance perfluorobutanesulfonic acid (PFBS) and its salts fulfil the criteria of a substance of very high concern, on the basis of Article 57 in the REACH legislation. The Norwegian Geotechnical Institute was asked to conduct a literature review on relevant physicochemical properties and environmental monitoring data to assist in this evaluation.

Physicochemical Properties

Physicochemical Properties of the potassium salt of PFBS (PFBS-K) and the neutral PFBS (PFBS) have been collected, both of which are currently registered in REACH (EC numbers 249-616-3 and 206-793-1, respectively). Many of the pure phase properties are extremely different between the salt and the neutral form, due to the influence of the crystal lattice energy of the salt. For environmental and biological distribution processes, however, the physicochemical properties of the neutral form are the most relevant, as well as their dependence on pH.

Degradation

PFBS is a perfluoroalkylsulfonate, which are amongst the most stable and persistent organic molecules possible. No studies have observed degradation of PFBS (or other perfluoroalkylsulfonates) under environmental conditions, including atmospheric photolysis. Reductive defluorination in anaerobic environments has been proposed as a pathway for environmental degradation; however, conclusive proof of this occurring in the environment has yet to be documented.

Environmental Distribution

Adsorption/Desorption – several studies have measured soil-water or sediment-water partitioning constants. The average log organic carbon-water partition coefficient, log Koc, from these studies is 2.2. Based on this value, it can be derived for a soil containing ca. 1% organic carbon that the concentration in soil (ng/kg) would be similar to that in water (ng/L), implying substantial mobility in the case of flowing water.

Volatilisation - PFBS is an anionic acid with a pH dependant air-water partition coefficient, log Kaw, that is too low to measure and is predicted be as low as -14.5 at pH 8. This indicates that volatilization from water is negligible, and that air-phase presence is due to direct PFBS emissions into the air of the substance itself or contaminated water droplets/particles.

Distribution Modelling - PFBS is expected to be mainly distributed in water, globally. This is confirmed by the monitoring data.

Monitoring Data

The compilation of monitoring data included 84 studies that were selected randomly. It is not considered exhaustive, therefore all results are to be taken within the context of these 84 studies and not the entire literature.
Humans – PFBS has been reported in blood samples throughout the world; there is also indication this concentration has been increasing (Glynn et al., 2012).

Atmosphere – PFBS is primarily detected in rain samples, max 1.54 ng/L (Kwok et al., 2010), rather than air samples, which is anticipated based on the low log Kaw.

Biota – PFBS has been detected in Arctic biota, indicating long range transport. However, levels found in Arctic biota are much smaller than longer chain perfluoroalkylsulfonic acids like perfluorohexanesulfonic acid (PFHxS) and perfluorooctanesulfonic acid (PFOS). It has also been detected in diverse marine, freshwater and terrestrial species. PFBS shows a tendency for enrichment in plants, likely due to uptake through the xylem.

Marine water – PFBS is ubiquitous in oceanic water, from the Arctic, maximum 0.11 ng/L (Kallenborn et al., 2004), to coastal waters, maximum 1.48 ng/L (Kwok et al., 2015).

Fresh water – PFBS is ubiquitous in fresh water systems, including Arctic snow and ice (max 2.15 ng/L). Areas away from suspected source zones (e.g. fluorochemical production facilities) could be contaminated up to 1450 ng/L (Skutlarek et al., 2006).

Drinking water -- In regions away from established PFAS source areas, substantial drinking water contamination can occur, with a France maximum of 15 ng/L (Schwanz et al., 2016), a German maximum of 26 ng/L (Wilhelm et al., 2010), an Italy maximum of 45 ng/L (IRSA-CNR, 2013), a Spain maximum of 69 ng/L (Ericson et al., 2009), a China maximum of 18 ng/L (Mak et al., 2009), and a Brazil maximum of 16 ng/L (Schwanz et al., 2016). These concentrations even exceed those of some known source zones, such as 19.0 ng/L measured in drinking water near a PFAS production facility in the Netherlands (Gebbink et al., 2017).

Soils and Sediments – Very little monitoring data could be found for soils and sediments; however, based on the proposed log Koc, the concentrations in typical soils and sediments (in ng/kg) would be similar to that found water (in ng/L).

Waste water and Leachate – Waste water and leachate are important emission sources to PFAS in the environment. The maximum waste water concentration of 26 ng/L (Ahrens et al., 2009b) was less than the maximum landfill leachate concentration 3410 ng/L (Lang et al. 2017).

Temporal trends/Comparisons with other PFAS
There are multiple indicators that PFBS concentrations in aquatic media are continuing to increase, to an extent they are beginning to surpass most other PFAS substances. This has been observed in several recent waste water emissions and various fresh water studies, in which PFBS is either the dominant PFAS or amongst the top three. Several biota studies are also noticing an increase in PFBS over time; however, concentrations
in biota remain much smaller than other PFAS, due in part to the low bioaccumulation potential.

**Data indicating long-range transport.**
The physicochemical properties for PFBS, in particular its extreme environmental persistence, along with its low log Koc and low log Kaw, collectively indicate that PFBS should enrich in the arctic overtime if emissions continue. The monitoring data collectively supports this expectation. The major transport pathway for PFBS in the environment is expected to through water, based on physicochemical properties. The ubiquity of PFBS in marine and freshwater isolated from known sources is support for this expectation. PFBS also appears ubiquitously in drinking water and bottled water, showing that it too can survive transport through filters and advanced treatment processes.

**Bioaccumulation.**
PFBS has been quantified in several biological matrices; however, generally at smaller concentrations than PFHxS and PFOS. To some extent this is explained by quicker excretion rates for PFBS. However if animals and humans are continuously exposed to increasing environmental concentrations of PFBS, the excretion pathway is less relevant, as biota would reach equilibrium with elevated exposure concentrations.
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## Appendix

Latin names of biota mentioned in this study.

## Review and reference page
1 Introduction

This report presents an overview of the physicochemical properties, monitoring data and environmental distribution of the substance perfluorobutanesulfonic acid (PFBS), IUPAC name (1,1,2,2,3,3,4,4,4-Nonafluorobutane-1-sulfonic acid).

Having 4 carbons in its molecular structure, this substances is referred to as a short chain perfluoroalkylsulfonate (PFAS). It was introduced to the market on a larger scale after the phase out of perfluorooctanesulfonic acid (PFOS), which had 8 carbons in its molecular structure. PFOS has been restricted due it being persistent, bioaccumulative and toxic in the environment (PFOS, 2004). Due to the increasing use of PFBS, and increasing number of reports of PFBS in the environment, the Norwegian Environment Agency is currently considering whether PFBS and its salts fulfil the criteria of a substance of very high concern, on the basis of Article 57 in REACH. The data in this report was generated to provide background information to this evaluation.

2 Physicochemical properties

PFBS being a short chain perfluoroalkylsulfonate (PFAS) having 4 carbons, has many general physicochemical properties that are similar to its longer chain-counterparts, such as the 6 carbon perfluorohexanesulfonic acid (PFHxS) PFHxS, 8 carbon carbon perfluorohexanesulfonic acid (PFOS) and other longer chain counter parts. In water PFBS is a strong acid, and predominantly dissociated as an anion. PFBS has excellent surfactant properties, having a hydrophilic anionic sulfonate head group, and hydrophobic perfluorinated end group.

In the pure phase, PFBS can be present as neutral liquid (molecular formula C₄F₉SO₃H) or as a crystalline salt (molecular formula C₄F₉SO₃X⁺). Under REACH both the neutral and potassium (K-salt) form have been registered (EC numbers 206-793-1 and 249-616-3, respectively). As is always the case, the pure phase properties like melting point, boiling point, density, physical state at STP, vapour pressure and water solubility are intrinsically dependant on whether they are determined for the neutral species or the salt. The properties of solid salts are dominated by the strength of the crystal lattice structure that the anions and cations arrange themselves in; therefore, for the PFBS anion, different counter-ions will result in different solid state properties (e.g. Na⁺PFBS⁻ has different pure phase properties than K⁺PFBS⁻). However, as neutral liquids do not have a crystal structure, their pure phase properties of PFBS-acid in the pure form are radically different than PFBS-salts.

For environmental partitioning properties, such as the octanol-water partition coefficient (Kow), air-water partition coefficient (Kaw), octanol-air partition coefficient (Koa), and organic carbon-water coefficient (Koc), these by definition are apply to the PFBS-acid/-anion only, and are independent of cation.
An important consideration however is that all properties involving water, such as water solubility, Kow, and Kaw, are dependent on pH. PFBS is an acid, and in water dissociates from the neutral form C₄F₉SO₃H to the anionic C₄F₉SO₃⁻ form. Over ambient pH ranges of acids and bases, there is a convention to use the symbol "D" instead of "K" for partitioning processes, to indicate the pH dependent "D"istribution of both the neutral and ionic species combined are being considered in the D value. In other words, the symbols Dow and Daw can be thought of as the pH-dependant Kow and Kaw values, respectively. In this nomenclature, Kow and Kaw are reserved for the neutral form only, and Dow, Daw and Doc are used for all relative fractions of the neutral and ionic forms. The pH dependence is governed by the acid-dissociation constant, pKa. For monoprotic acids like PFBS, this pH dependence can be quantified using the following equations:

\[
Dow = \frac{Kow}{1+10^{pH-pKa}} \quad (1)
\]
\[
Daw = \frac{Kaw}{1+10^{pH-pKa}} \quad (2)
\]

An overview of the properties of the PFBS-K salt and PFBS is presented in Table 1. A discussion of specific properties is presented further below.

Table 1: Overview of physiochemical properties of PFBS and the PFBS-K salt

<table>
<thead>
<tr>
<th>Property</th>
<th>Salt/Neutral Form</th>
<th>Description of key information</th>
<th>Reference/source of information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical state at 20°C and 101.3 kPa</td>
<td>PFBS-K salt</td>
<td>White powder</td>
<td>Experimental, REACH registration dossier, September 2018 (EC: 249-616-3)</td>
</tr>
<tr>
<td>Melting/freezing point</td>
<td>PFBS-K salt</td>
<td>&gt; 280 °C</td>
<td>Experimental, REACH registration dossier, September 2018 (EC: 249-616-3)</td>
</tr>
<tr>
<td></td>
<td>PFBS</td>
<td>-21 °C</td>
<td>Experimental, REACH registration dossier, September 2018 (EC: 206-793-1)</td>
</tr>
<tr>
<td>Boiling point</td>
<td>PFBS-K salt</td>
<td>Decomposes before boiling</td>
<td>Experimental, REACH registration dossier, September 2018 (EC: 249-616-3)</td>
</tr>
<tr>
<td>Property</td>
<td>Salt/Neutral Form</td>
<td>Description of key information</td>
<td>Reference/source of information</td>
</tr>
<tr>
<td>---------------</td>
<td>-------------------</td>
<td>-----------------------------------------</td>
<td>-------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Vapour pressure</td>
<td>PFBS-K salt</td>
<td>$&lt; 1.22E-05 \text{ Pa at } 20^\circ \text{C} \pm 1^\circ \text{C}$</td>
<td>Experimental, REACH registration dossier, September 2018 (EC: 249-616-3)</td>
</tr>
<tr>
<td></td>
<td>PFBS</td>
<td>$7 \text{ Pa at } 20^\circ \text{C}$</td>
<td>Experimental, REACH registration dossier, September 2018 (EC: 206-793-1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$2.8 \text{ Pa}$</td>
<td>(Wang et al., 2011) Estimated using COSMOTHERM</td>
</tr>
<tr>
<td>Density</td>
<td>PFBS-K salt</td>
<td>$2.248 \text{ g/cm}^3 \text{ at } 20^\circ \text{C}$</td>
<td>Experimental, REACH registration dossier, September 2018 (EC: 249-616-3)</td>
</tr>
<tr>
<td></td>
<td>PFBS</td>
<td>$1.824 \text{ g/cm}^3 \text{ at } 20^\circ \text{C}$</td>
<td>Experimental, REACH registration dossier, September 2018 (EC: 206-793-1)</td>
</tr>
<tr>
<td>Water solubility</td>
<td>PFBS-K salt</td>
<td>$54.6 \text{ g/mL at } 22.5-24^\circ \text{C}$</td>
<td>REACH registration dossier, September 2018 (EC: 249-616-3; 3M Environmental Laboratory (2001) Characterisation Study PFBS: a.) Primary Standard – Test Control Reference #TCR-99030-023 (lot 101), b.) Test Control Reference #TCR-00017-071 (Lot 102) Phase: Solubility Determination. 3M Environmental Laboratory Study #FACT-TCR009 (LIMS #E00-1877), 28 March 2001. 3M Environmental Laboratory Minnesota (unpublished report submitted by the 3M Corporation)</td>
</tr>
<tr>
<td>Property</td>
<td>Salt/Neutral Form</td>
<td>Description of key information</td>
<td>Reference/source of information</td>
</tr>
<tr>
<td>----------------------------------------------</td>
<td>-------------------</td>
<td>-------------------------------------------------------------------------------------------------</td>
<td>---------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td></td>
<td>PFBS</td>
<td>Fully miscible at 20°C</td>
<td>Experimental, REACH registration dossier, September 2018 (EC: 206-793-1). This conclusion is also expected over the entire ambient pH range based on an estimated water solubility of the neutral species (30 g/L) and the estimated pKa of -3.94</td>
</tr>
<tr>
<td>Partitioning coefficient soil/water (log Koc)</td>
<td>PFBS-K salt</td>
<td>&lt; 2</td>
<td>REACH registration dossier, September 2018 (EC: 249-616-3)</td>
</tr>
<tr>
<td></td>
<td>PFBS</td>
<td>2.2</td>
<td>Average of three experimental values, from (Kwadijk et al. 2010; Guelfo &amp; Higgins, 2013; Vierke et al., 2014)</td>
</tr>
<tr>
<td>Dissociation constant pKₐ</td>
<td>PFBS</td>
<td>-3.94</td>
<td>(Wang et al., 2011) Estimated using COSMOtherm, which is one of the best models for PFAS (Goss, 2008). Estimations using the SPARC method gave a value of 0.14.</td>
</tr>
<tr>
<td></td>
<td>PFBS-K salt</td>
<td>-1.8 at 23 °C</td>
<td>Experimental, REACH registration dossier, September 2018 (EC: 249-616-3)</td>
</tr>
<tr>
<td>Partition coefficient n-octanol/water (log Kow / pH dependent Dow value)</td>
<td>PFBS</td>
<td>3.9 (neutral form) -4.0 to 0.0 (pH 4) -7.0 to -3.0 (pH 7) -8.0 to -4.0 (pH 8)</td>
<td>Estimated using COSMOtherm (Wang et al. 2011) along with the estimated pKas -3.94 and 0.14, respectively, and the equation Dow = (1/(1+10^(pH – pKa)))Kow (for monoprotic acids)</td>
</tr>
<tr>
<td>Property</td>
<td>Salt/Neutral Form</td>
<td>Description of key information</td>
<td>Reference/source of information</td>
</tr>
<tr>
<td>----------</td>
<td>------------------</td>
<td>--------------------------------</td>
<td>--------------------------------</td>
</tr>
<tr>
<td>Partition coefficient air/water (log (K_{aw}/pH) dependant (D_{aw}) value)</td>
<td>PFBS</td>
<td>-2.59 (pH &lt;&lt; 0)</td>
<td>(Wang et al., 2011) estimated for neutral (nonionized species) using COSMOTHERM</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-2.6 (neutral form)</td>
<td>Estimated using (\log K_{aw}) of -2.6 for the neutral species and pKa -3.94 and 0.14, respectively, and the equation (D_{aw} = (1/(1+10^{(pH – pKa)}))K_{aw}) (for monoprotic acids)</td>
</tr>
<tr>
<td>Partitioning coefficient n-octanol/air (log (K_{oa}))</td>
<td>PFBS</td>
<td>6.49</td>
<td>(Wang et al., 2011) estimated using COSMOTHERM</td>
</tr>
</tbody>
</table>

### 3 Degradation

PFBS, like other perfluoroalkylsulfonates, are amongst the most stable and persistent organic molecules possible (Stock et al. 2010). The main reason for this is the thermodynamic stability of the C-F bonds (with bond dissociation energies of 484 kJ/mole or larger) and the F₂CF-SO₃ bonds, which are amongst the strongest bonds that carbon can make. Under aerobic, environmental conditions, replacing them is thermodynamically unfavourable, requiring energies that are typically not available without additional energy or some form of catalysis (Vecitis et al., 2009). Similarly, the S in the sulphonate end group is at its maximum oxidation state, and cannot be oxidized further.

Quinette et al. (2010) tested for the degradation of PFBS using advanced oxidation processes through ultraviolet radiation, hydrogen peroxide, or both, followed by conventional tests, such as the manometric respirometry test (OECD 301 F; OxiTop), closed-bottle test (OECD 301 D), and standardized fixed-bed bioreactor; the study concluded that "PFBS is not biodegradable", with no significant degradation being observed under test conditions. The most theoretically plausible degradation pathway for PFBS is through reductive defluorination, which occurs under anaerobic conditions (Parsons et al. 2008). Mechanistic pathways for reductive defluorination have been established (Park et al. 2009). Parsons et al. (2008) conducted a review of biodegradation studies of PFOS, and concluded that no biodegradation has been observed in aerobic conditions, though there has been some observations of degradation of PFOS under anaerobic conditions (though no metabolites was measured in these studies). It cannot be ruled out that some degradation of PFBS under anaerobic conditions can occur (e.g. in hypoxic groundwater, marine water or sediments); however, the rates of these under environmental conditions are unknown, and potentially very slow or negligible, and have yet to be observed in the environment.
Photolysis of perfluoroalkylsulfonates in the atmosphere is generally considered negligible under environmental conditions (Vecitis et al., 2009). An outlying study is one by Taniyasu et al. (2013) which reported observing photolysis in air at high altitudes (>2500m) of PFOS, which reacted via dealkylation to form PFBS via dealkylation. However, they also concluded that PFBS was more recalcitrant and stable. It should be noted that these PFOS results have been disputed by Wang et al. (2015), who argue that PFOS is too stable to undergo atmospheric photolysis. Nevertheless, PFBS in particular is considered to remain stable to photolysis under environmental conditions, and this has been supported by all studies thus far.

In conclusion, to date no studies have observed degradation of PFBS (or other perfluoroalkylsulfonates) under environmental conditions.

4 Environmental Distribution

4.1 Adsorption/Desorption

For organic ions, like PFBS, conceptualizing sorption/desorption to soil is more complex than neutral organic molecules. For neutral organic molecules, one has to consider mainly van der Waal type interactions (non-ionic sorption interactions). For ionic substances, one has to additionally consider ionic interactions between the substance and soil. Soils exhibit wide variation in their anion exchange capacity (AEC), and hence their ability to retain anionic-charged molecules like PFBS.

Though adsorption/desorption to soils is commonly normalized to the organic carbon fraction, i.e. Koc value, a common discussion point regarding the adsorption/sorption of ions is the role of clays and minerals (Droge et al 2013). Clays and minerals can have widely differing available surface areas for sorption and AEC values. It is therefore challenging to include a generic parameter to account for clay sorption.

Three studies that determined log Koc values for naturally occurring soils and sediments are Guelfo & Higgen (2013), Kwadijk et al. (2010) and Vierke et al. (2014). Guelfo & Higgen (2013) and studied the sorption of different Aqueous Film Forming Foam to different types of soil, and reported a narrow band of log Koc values (1.79 ± 0.10), though a wide range of log Kd values (-0.55 to 0.21). Kwadijk et al. (2010) examined the sorption of PFAS contaminated areas in the Netherlands and derived a log Koc of 2.2, and a distribution of log Kd from 1.42 ± 0.50. Vierke et al. (2014) reported a log Koc of 2.7 from column tests. Here the average log Koc from these studies of 2.2 is considered.

One can infer from a log Koc of 2.2 (or a Koc of 158 l/kg) that PFBS is quite mobile in the aquatic environment. For instance, if we consider the definition of Koc
Koc = \frac{c_{\text{soil}}}{(c_{\text{water}} \times f_{\text{OC}})} \quad (3)

Where \( c_{\text{soil}} \) (ng/kg) is the soil concentration, \( c_{\text{water}} \) (ng/L) is the water concentration and \( f_{\text{OC}} \) the fraction of organic carbon. At 1% \( f_{\text{OC}} \):

\[
c_{\text{sediment}} \ (\text{ng/kg}) = Koc \times c_{\text{water}} \times 0.01 \text{organic carbon} = 1.58 \ c_{\text{water}} \ (\text{ng/L})
\]

Therefore, the concentration of PFBS in water per L is expected to be roughly similar to soil or sediment per kg. As a result, when water flows through soil, the PFBS can be readily transported compared to substances with a higher log Koc value.

4.2 Volatilisation

PFBS-K salts do not volatilize, but neutral PFBS does volatilize to ca 2.8-7 Pa. This implies that traces of PFBS fumes would be present in a room containing neutral PFBS and poor ventilation. For air-water partitioning, the pH dependant air-water partition coefficient, \( \log D_{\text{aw}} \), is too low to measure and is predicted be as low as -14.5 at pH 8 (Table 1). This indicates that volatilization from water is negligible; at pH 8, essentially all PFBS is ionic, and it would be exclusively in water.

Because of negligible volatilization of PFBS, its presence in the air would be primarily due to direct emissions of the substance or its salts into the air. Another possibility is through emissions of contaminated particles or water droplets (e.g. contaminated marine aerosols). When PFBS is in the atmosphere, it is expected to readily partition with surface water and water droplets (rain, cloud droplets, fog droplets, etc.) based on this extremely low log \( K_{\text{aw}}/D_{\text{aw}} \) value, and therefore undergo efficient removal from the atmosphere via wet-deposition.

4.3 Distribution modelling

Distribution modelling of anionic substances like PFBS and other PFAS is not straightforward. Most distribution models were developed for neutral substances, wherein distribution modelling is generally described using three main partitioning coefficients: \( K_{\text{ow}}, K_{\text{oa}} \) and \( K_{\text{aw}} \). However, "octanol" as a surrogate phase for soil/sediment/aerosol organic matter, or biological membranes, is inappropriate for anionic substances like PFBS, because octanol cannot make ionic interactions. One approach that has been used with PFOS is to use the experimental Koc value in distribution modelling, rather than the \( K_{\text{ow}} \) (Armitage et al. 2009), as the experimental Koc inherently includes some ionic interactions to a naturally occurring phase. In this case, basic distribution modelling can be done using the pH dependant \( K_{\text{aw}}, K_{\text{oc}} \) and the organic carbon-air partitioning coefficient \( K_{\text{oc,a}} \). For perfluoroalkylsulphonates, values for these terms are presented in Table 2.
Table 2. Physiochemical properties needed to estimate environmental distribution

<table>
<thead>
<tr>
<th>Parameter</th>
<th>PFBS</th>
<th>PFHxS</th>
<th>PFOS</th>
<th>PFDS</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>log Kaw (neutral)</td>
<td>-2.6</td>
<td>-2.4</td>
<td>-1.7</td>
<td>-1.2</td>
<td>(Wang et al. 2011)</td>
</tr>
<tr>
<td>log Daw (pH 8)</td>
<td>-14.5</td>
<td>-13.8</td>
<td>-13.1</td>
<td>-12.0</td>
<td>Derived (Wang et al. 2011)</td>
</tr>
<tr>
<td>log Koc</td>
<td>2.2</td>
<td>2.6</td>
<td>3.0</td>
<td>3.4</td>
<td>PFBS (Kwadijk et al. 2012), PFOS (Zareitalablad, 2010), PFHxS and PFDS extrapolated (read-across)</td>
</tr>
<tr>
<td>log Koc,a</td>
<td>4.8</td>
<td>5.0</td>
<td>4.7</td>
<td>4.6</td>
<td>Calculated from the thermodynamic triangle: log Koc,a = log Koc - log Kaw</td>
</tr>
</tbody>
</table>

As evident from Table 2, the range in log Daw, log Kow and log Koc,a values are quite similar between these PFAS. The spread in log Koc,a is only from 4.7 (PFOS) to 5.0 (PFHxS). For log Daw, the values for all species are so negative, that this means volatilization is similarly negligible. The log Koc values spread from 2.2 (PFBS) to 3.4 (PFDS), which would imply PFDS, PFOS and PFHxS sorb than PFBS by factors of 16, 6 and 2.5 respectively. Thus, the difference between PFHxS and PFBS sorption to negligible is relatively minor compared to, e.g. heterogeneity of sorpting phases in soil.

The Globo-POP model (Wania et al. 2007) has been established to model the global distribution neutral substances. In Figure 1 below, output from the Globo-POP model is used to illustrate the partitioning properties of substances that, globally, are predominantly in the air, water or soil phases, based on the following assumptions: the substance is non-degradable (which is appropriate for PFBS), 10 years of continuous emissions has occurred, emissions occur equally to soil, water, air (1/3rd each), and the global distribution of emissions is zonally distributed similarly to the human population. On this Figure, lines are overlaid that represented the physical chemical properties of PFBS, PFHxS, PFOS and PFDS (Table 2), though using Koc,a instead of Koa, and the pH dependence of the Daw.

As is indicated by this Figure, PFBS is tightly clustered along with PFHxS, PFOS and PFDS, to indicate they are primarily in the water phase.
Figure 1. Global POP chemical space distribution for non-degradable substances being emitted into air-water-soil at equal levels for the 10 years, with a similar zonal distribution the human population. The location of PFBS, PFHxS, PFOS and PFDS is overlaid, using log Koc instead of log Koa and considering the pH dependence of log Kaw. Note that at ambient pH, the log Kaw is even lower than presented in this chart, and the substances would be strongly within the sea and freshwater media area of the chart. Other substances presented in this figure for comparison are CBzs (Chlorobenzenes), PCBs (polychlorinated biphenyls) and PCDDs and PCDFs (Dioxins). This Figure is modified and reprinted with permission from Wania (2003). Copyright 2003 American Chemical Society.
4.4 Monitoring Data

There are numerous studies reporting PFBS data in the environment; herein a compilation of some of this data from a dataset of 84 diverse peer-reviewed scientific research papers, thesis and reports is presented. No target environmental media was used in this search. Future work could expand this compilation, particularly as more data becomes available.

PFBS concentration data were sorted into the following media: air, rain, surface water, marine water, drinking water, ground water, soil, sediment, waste water treatment plants, landfills, marine biota, freshwater biota, terrestrial biota (non plants), terrestrial plants and humans. Further, marine biota and fresh water data for Arctic/Antarctic regions is presented separately, as several studies in this compilation were focused on such analysis. Further, some other studies were focussed near known PFBS sources (e.g. PFAS production facilities, airports, textile industries). Concentrations in these area should not be considered representative of typical environmental concentrations. Therefore, such data are marked, and in the case of fresh water, presented separately.
4.4.1 Humans

Blood samples have been analysed in Europa and China. PFBS was not detected in a 2009 German blood study (Yeung et al., 2013), though it was in an Italian study (max 0.36 and 4.26 ng/g for non-exposed and exposed populations in the Veneto region (Ingelidoa et al., 2018)), and with high frequency pregnant and primiparous mothers in Uppsala, Sweden (means from 0.03-0.08 ng/L, max 0.80 ng/L) (Gyllenhammar et al., (2015) and Glynn et al., (2012)). Shanghai cord blood samples from Shanghai contained a max of 0.46 ng/L (Wang et al., 2016). Near the PFAS production facility in Fuxin a max of 1.3 ng/L was reported (Bao et al., 2010). A study in Spain (Pérez et al., 2013) examined PFAS levels in 99 samples of autopsy tissues and found highest levels in the lung (17.8 ng/L) and kidney (8 ng/L).

Table 16. Concentrations of PFBS in human samples (ng/g ww)

<table>
<thead>
<tr>
<th>Region</th>
<th>Location</th>
<th>Year</th>
<th>Mean +/- SD</th>
<th>Min-Maks(Median)</th>
<th>n (det. Freq)</th>
<th>Remark</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Europe</td>
<td>Germany, Halle and Münster</td>
<td>1982-2009</td>
<td>nd</td>
<td>&lt;LOQ</td>
<td>257 (31 %)</td>
<td>Blood plasma</td>
<td>(Yeung et al., 2013)</td>
</tr>
<tr>
<td>Europe</td>
<td>Italy, Veneto</td>
<td>2018</td>
<td>&lt;LOQ</td>
<td>&lt;LOQ - 4.26 (&lt;LOQ)</td>
<td>250 (18 %)</td>
<td>Blood (exposed areas)</td>
<td>(Ingelidoa et al., 2018)</td>
</tr>
<tr>
<td>Europe</td>
<td>Italy, Veneto</td>
<td>2018</td>
<td>&lt;LOQ</td>
<td>&lt;LOQ - 0.36 (&lt;LOQ)</td>
<td>250 (18 %)</td>
<td>Blood (non-exposed areas)</td>
<td>(Ingelidoa et al., 2018)</td>
</tr>
<tr>
<td>Europe</td>
<td>Spain, Tarragona</td>
<td>2008</td>
<td>0.9</td>
<td></td>
<td></td>
<td>Liver</td>
<td>(Pérez et al., 2013)</td>
</tr>
<tr>
<td>Europe</td>
<td>Spain, Tarragona</td>
<td>2008</td>
<td>3.2</td>
<td></td>
<td></td>
<td>Bone</td>
<td>(Pérez et al., 2013)</td>
</tr>
<tr>
<td>Europe</td>
<td>Spain, Tarragona</td>
<td>2008</td>
<td>&lt;LOD</td>
<td></td>
<td></td>
<td>Brain</td>
<td>(Pérez et al., 2013)</td>
</tr>
<tr>
<td>Europe</td>
<td>Spain, Tarragona</td>
<td>2008</td>
<td>17.8</td>
<td></td>
<td></td>
<td>Lung</td>
<td>(Pérez et al., 2013)</td>
</tr>
<tr>
<td>Europe</td>
<td>Spain, Tarragona</td>
<td>2008</td>
<td>8</td>
<td></td>
<td></td>
<td>Kidney</td>
<td>(Pérez et al., 2013)</td>
</tr>
<tr>
<td>Europe</td>
<td>Sweden, Uppsala</td>
<td>1996-1999</td>
<td>0.03 ± 0.00</td>
<td>&lt;MDL - 0.21 (0.02)</td>
<td>132 (77 %)</td>
<td>Blood serum pregnant mothers (1996-1999)</td>
<td>(Gyllenhammar et al., 2015)</td>
</tr>
<tr>
<td>Europe</td>
<td>Sweden, Uppsala</td>
<td>2008-2011</td>
<td>0.06 ± 0.01</td>
<td>&lt;MDL - 0.80 (0.03)</td>
<td>134 (86 %)</td>
<td>Blood serum pregnant mothers (2008-2011)</td>
<td>(Gyllenhammar et al., 2015)</td>
</tr>
<tr>
<td>Europe</td>
<td>Sweden, Uppsala</td>
<td>1996-2010</td>
<td>0.08 ± 0.02</td>
<td>0.05 - 0.10 (0.09)</td>
<td>6 (100 %)</td>
<td>Blood serum primiparous mothers</td>
<td>(Glynn et al., 2012)</td>
</tr>
<tr>
<td>Asia</td>
<td>China, Shanghai</td>
<td>2011-2012</td>
<td>0.053</td>
<td>LOD - 0.46 (0.05)</td>
<td>686 (97 %)</td>
<td>Cord blood</td>
<td>(Wang et al., 2016)</td>
</tr>
<tr>
<td>Asia</td>
<td>China, Fuxin</td>
<td>2009</td>
<td>0.19 ± 0.22</td>
<td>0.01 - 1.30 (0.12)</td>
<td>120 (93 %)</td>
<td>Human blood</td>
<td>(Bao et al., 2010)</td>
</tr>
</tbody>
</table>
Figure 14. Concentrations of PFBS in human samples (ng/g ww)
PFBS has been reported in atmospheric samples at trace levels throughout the world, though mostly in rain. It has been detected in Arctic air in one study (Alert, Greenland at 0.1 ± 0.2 pg/m³). The highest reported concentration in rain was in Hong Kong, at 1.54 ng/L. Due to tendency for PFBS to prefer water to air (based on the Kₐw value), air emissions are likely prone to wet deposition, by partitioning with clouds and rain droplets (see section 4.2).

**Table 4. Environmental concentrations of PFBS in air (pg/m³) and rain (ng/L)**

<table>
<thead>
<tr>
<th>Region</th>
<th>Location</th>
<th>Year</th>
<th>Mean +/- SD</th>
<th>Min-Maks(Median)</th>
<th>n (det. Freq)</th>
<th>Units</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arctic</td>
<td>Alert, Greenland (Air)</td>
<td>2006-2015</td>
<td>0.1 ± 0.2</td>
<td>BDL - 1.5 (0.0)</td>
<td>169 (66 %)</td>
<td>pg/m³</td>
<td>(Wong et al., 2018)</td>
</tr>
<tr>
<td>Arctic</td>
<td>Zeppelin, Svalbard (Air)</td>
<td>2006-2015</td>
<td>nd</td>
<td></td>
<td>383</td>
<td>pg/m³</td>
<td>(Wong et al., 2018)</td>
</tr>
<tr>
<td>North America</td>
<td>Canada (Landfill Air)</td>
<td>2009</td>
<td>nd</td>
<td></td>
<td>nd</td>
<td>pg/m³</td>
<td>(Ahrens et al., 2011)</td>
</tr>
<tr>
<td>Europe</td>
<td>Finland (Rain)</td>
<td>2004</td>
<td>nd</td>
<td></td>
<td>2</td>
<td>ng/L</td>
<td>(Kallenborn et al., 2004)</td>
</tr>
<tr>
<td>Europe</td>
<td>Sweden (Rain)</td>
<td>2004</td>
<td>nd</td>
<td></td>
<td>4</td>
<td>ng/L</td>
<td>(Kallenborn et al., 2004)</td>
</tr>
<tr>
<td>Europe</td>
<td>Toulouse, France (Rain)</td>
<td>2008</td>
<td>&lt;0.05</td>
<td></td>
<td></td>
<td>ng/L</td>
<td>(Kwok et al., 2010)</td>
</tr>
<tr>
<td>Asia</td>
<td>Hong Kong (Rain)</td>
<td>2007</td>
<td>1.54</td>
<td>&lt;0.05 - 1.5</td>
<td></td>
<td>ng/L</td>
<td>(Kwok et al., 2010)</td>
</tr>
<tr>
<td>Asia</td>
<td>Kawaguchi, Japan (Rain)</td>
<td>2006-2008</td>
<td>0.24</td>
<td>&lt;0.05 - 1.7</td>
<td></td>
<td>ng/L</td>
<td>(Kwok et al., 2010)</td>
</tr>
<tr>
<td>Asia</td>
<td>Patna, India (Rain)</td>
<td>2008</td>
<td>&lt;0.05</td>
<td></td>
<td></td>
<td>ng/L</td>
<td>(Kwok et al., 2010)</td>
</tr>
<tr>
<td>Asia</td>
<td>Tsukuba, Japan (Rain)</td>
<td>2006-2008</td>
<td>0.16</td>
<td>&lt;0.05 - 2.0</td>
<td></td>
<td>ng/L</td>
<td>(Kwok et al., 2010)</td>
</tr>
<tr>
<td>North America</td>
<td>Albany, USA (Rain)</td>
<td>2006-2007</td>
<td>&lt;0.05</td>
<td></td>
<td></td>
<td>ng/L</td>
<td>(Kwok et al., 2010)</td>
</tr>
<tr>
<td>North America</td>
<td>Slingerlands, USA (Rain)</td>
<td>2006-2007</td>
<td>0.1</td>
<td>&lt;0.05 - 0.6</td>
<td></td>
<td>ng/L</td>
<td>(Kwok et al., 2010)</td>
</tr>
</tbody>
</table>

BDL = below detection limit
Figure 2. Environmental concentrations of PFBS in rain (ng/L).
4.4.3 Biota

4.4.3.1 Arctic – marine

Prior to 2012, the majority of studies on arctic marine biota in this compilation did not report PFBS in Arctic Biota above detection limits. In more recent studies, it is starting to appear more frequently. A study on samples collected between 2012-2013 (Gebbink et al. 2016b) quantified PFBS in the livers of polar bears and killer whales from Greenland, at concentrations of 0.03 and 0.01 ng/g ww respectively. Further, PFBS has also been reported in polar bear plasma from Svalbard in two separate studies, the first for samples collected between 2000-2014 having a mean concentration of 0.27 ng/g ww (Routti et al., 2017) though with no clear time trend, the second for samples collected in 2017 having a mean of 0.04 ng/g ww (Miljødirektoratet, 2018). It has also been reported in mink liver (mean 0.19 ng/g ww) and common gull liver (mean 0.03 ng/g ww).

Table 5. Environmental concentrations of PFBS in arctic biota (ng/g ww). See Appendix A1 for Latin names.

<table>
<thead>
<tr>
<th>Region</th>
<th>Location</th>
<th>Date</th>
<th>Mean +/- SD</th>
<th>Min-Maks (Median)</th>
<th>n (det. Freq)</th>
<th>Remark a)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arctic</td>
<td>Greenland</td>
<td>2012-2013</td>
<td>&lt;0.002</td>
<td>nd</td>
<td>10</td>
<td>Ringed seal liver</td>
<td>(Gebbink et al., 2016b)</td>
</tr>
<tr>
<td>Arctic</td>
<td>Greenland</td>
<td>2012-2013</td>
<td>0.03 ± 0.01</td>
<td>0.01 ± 0.00</td>
<td>8 (100 %)</td>
<td>Polar bear liver</td>
<td>(Gebbink et al., 2016b)</td>
</tr>
<tr>
<td>Arctic</td>
<td>Greenland</td>
<td>2012-2013</td>
<td>0.03 ± 0.01</td>
<td>0.01 ± 0.00</td>
<td>6 (66 %)</td>
<td>Killer whale liver</td>
<td>(Gebbink et al., 2016b)</td>
</tr>
<tr>
<td>Arctic</td>
<td>Hornøya</td>
<td>1983</td>
<td>&lt;0.009</td>
<td>nd</td>
<td>5</td>
<td>Herring Gull egg</td>
<td>(Verreault et al., 2007)</td>
</tr>
<tr>
<td>Arctic</td>
<td>Hornøya</td>
<td>1993</td>
<td>&lt;0.009</td>
<td>nd</td>
<td>5</td>
<td>Herring Gull egg</td>
<td>(Verreault et al., 2007)</td>
</tr>
<tr>
<td>Arctic</td>
<td>Hornøya</td>
<td>2003</td>
<td>&lt;0.009</td>
<td>nd</td>
<td>5</td>
<td>Herring Gull egg</td>
<td>(Verreault et al., 2007)</td>
</tr>
<tr>
<td>Arctic</td>
<td>Nunavut, Canada</td>
<td>1972-2005</td>
<td>nd</td>
<td>nd</td>
<td>184</td>
<td>Ringed Seal liver</td>
<td>(Butt et al., 2008)</td>
</tr>
<tr>
<td>Arctic</td>
<td>Røst</td>
<td>1983</td>
<td>&lt;0.009</td>
<td>nd</td>
<td>5</td>
<td>Herring Gull egg</td>
<td>(Verreault et al., 2007)</td>
</tr>
<tr>
<td>Arctic</td>
<td>Røst</td>
<td>1993</td>
<td>&lt;0.009</td>
<td>nd</td>
<td>5</td>
<td>Herring Gull egg</td>
<td>(Verreault et al., 2007)</td>
</tr>
<tr>
<td>Arctic</td>
<td>Røst</td>
<td>2003</td>
<td>&lt;0.009</td>
<td>nd</td>
<td>5</td>
<td>Herring Gull egg</td>
<td>(Verreault et al., 2007)</td>
</tr>
<tr>
<td>Arctic</td>
<td>Røst</td>
<td>2017</td>
<td>&lt;0.06</td>
<td>nd</td>
<td>5</td>
<td>European shag eggs</td>
<td>(Miljødirektoratet, 2018)</td>
</tr>
<tr>
<td>Location</td>
<td>Region</td>
<td>Date 1</td>
<td>Date 2</td>
<td>Concentration</td>
<td>Organism</td>
<td>Literature Source</td>
<td></td>
</tr>
<tr>
<td>----------</td>
<td>--------</td>
<td>--------</td>
<td>--------</td>
<td>---------------</td>
<td>----------</td>
<td>------------------</td>
<td></td>
</tr>
<tr>
<td>Arctic</td>
<td>Svalbard</td>
<td>1990-2010</td>
<td>&lt;0.07</td>
<td>0.08 - 0.69 (0.27)</td>
<td>Ringed seal plasma</td>
<td>(Routti et al., 2016)</td>
<td></td>
</tr>
<tr>
<td>Arctic</td>
<td>Svalbard</td>
<td>2000-2014</td>
<td>0.27</td>
<td>70 (100 %)</td>
<td>Polar bear plasma</td>
<td>(Routti et al., 2017)</td>
<td></td>
</tr>
<tr>
<td>Arctic</td>
<td>Svalbard</td>
<td>2007</td>
<td>nd</td>
<td>Black guillemots liver</td>
<td>(Axelson et al., 2014)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arctic</td>
<td>Svalbard</td>
<td>2007</td>
<td>nd</td>
<td>Glaucus gull liver</td>
<td>(Axelson et al., 2014)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arctic</td>
<td>Svalbard</td>
<td>2016</td>
<td>nd</td>
<td>Ringed seal liver</td>
<td>(Schlabach et al., 2017)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arctic</td>
<td>Svalbard</td>
<td>2016</td>
<td>nd</td>
<td>Polar bear whole blood</td>
<td>(Schlabach et al., 2017)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arctic</td>
<td>Svalbard</td>
<td>2017</td>
<td>&lt;0.05</td>
<td>10</td>
<td>Common eider eggs</td>
<td>(Miljødirektoratet, 2018)</td>
<td></td>
</tr>
<tr>
<td>Arctic</td>
<td>Svalbard</td>
<td>2017</td>
<td>&lt;0.07</td>
<td>5</td>
<td>Kittiwake eggs</td>
<td>(Miljødirektoratet, 2018)</td>
<td></td>
</tr>
<tr>
<td>Arctic</td>
<td>Svalbard</td>
<td>2017</td>
<td>&lt;0.08</td>
<td>5</td>
<td>Glaucus gull eggs</td>
<td>(Miljødirektoratet, 2018)</td>
<td></td>
</tr>
<tr>
<td>Arctic</td>
<td>Svalbard</td>
<td>2017</td>
<td>0.04 ± 0.02</td>
<td>0.02 - 0.08 (0.04)</td>
<td>10 (60 %)</td>
<td>Polar bear plasma</td>
<td>(Miljødirektoratet, 2018)</td>
</tr>
<tr>
<td>Arctic</td>
<td>Troms</td>
<td>2013-2014</td>
<td>0.19 ± 0.11</td>
<td>0.07 - 0.33 (0.19)</td>
<td>10 (100 %)</td>
<td>Mink liver</td>
<td>(Miljødirektoratet, 2018)</td>
</tr>
<tr>
<td>Arctic</td>
<td>Tromsøya</td>
<td>2017</td>
<td>0.03 ± 0.03</td>
<td>0.01 - 0.07 (0.02)</td>
<td>5 (80 %)</td>
<td>Common gull egg</td>
<td>(Miljødirektoratet, 2018)</td>
</tr>
</tbody>
</table>

a) See Appendix Table A1 for Latin Names. nd = not detected
Figure 3. Environmental concentrations of PFBS in arctic marine biota (ng/g ww).
### 4.4.3.2 Marine

In non-arctic areas, PFBS has been reported in several marine biota samples throughout the world. The largest concentration was found in shark liver (*Sphyrna tiburo* or *Rhizoprionodon terraenovae*) at a mean of 0.7 ng/g ww and max of 2.1 ng/g ww (Green et al., 2016). The largest concentration found for turtles was in green turtle plasma (*Chelonia mydas*), at a mean of 0.09 and a max of 0.85 ng/g ww (Keller et al., 2012).

**Table 6. Environmental concentrations of PFBS in marine biota from other regions than the arctic (ng/g ww). See Appendix A1 for Latin names.**

<table>
<thead>
<tr>
<th>Region</th>
<th>Location</th>
<th>Date</th>
<th>Mean +/- SD</th>
<th>Min-Maks (Median)</th>
<th>n (det. Freq)</th>
<th>Remark</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Europe</td>
<td>Baltic sea</td>
<td>2013-2014</td>
<td>0.002</td>
<td></td>
<td>Zooplankton</td>
<td>(Gebbink et al., 2016a)</td>
<td></td>
</tr>
<tr>
<td>Europe</td>
<td>Baltic sea</td>
<td>2013-2014</td>
<td>0.01</td>
<td></td>
<td>Herring whole fish</td>
<td>(Gebbink et al., 2016a)</td>
<td></td>
</tr>
<tr>
<td>Europe</td>
<td>Baltic sea</td>
<td>2013-2014</td>
<td>0.06</td>
<td></td>
<td>Sprat whole fish</td>
<td>(Gebbink et al., 2016a)</td>
<td></td>
</tr>
<tr>
<td>Europe</td>
<td>Baltic sea</td>
<td>2013-2014</td>
<td>0.004 ± 0.000</td>
<td>(100 %)</td>
<td>Guillemot egg</td>
<td>(Gebbink et al., 2016a)</td>
<td></td>
</tr>
<tr>
<td>Europe</td>
<td>Black Sea</td>
<td>1997-1998</td>
<td>nd</td>
<td></td>
<td>Harbor porpoise organs</td>
<td>(Van de Vijver et al., 2007)</td>
<td></td>
</tr>
<tr>
<td>Europe</td>
<td>Faroe Islands</td>
<td>1986-2013</td>
<td>&lt;0.01</td>
<td></td>
<td>Pilot whale muscle</td>
<td>(Dassuncao et al., 2017)</td>
<td></td>
</tr>
<tr>
<td>Europe</td>
<td>Norway</td>
<td>2015</td>
<td>0.1</td>
<td>(0.10)</td>
<td>128</td>
<td>Cod liver</td>
<td>(Green et al., 2016)</td>
</tr>
<tr>
<td>Europe</td>
<td>Spain</td>
<td>2009</td>
<td>nd</td>
<td></td>
<td>Fish and shellfish (composite samples)</td>
<td>(Domingo et al., 2012)</td>
<td></td>
</tr>
<tr>
<td>North America</td>
<td>Minnesota/Mississippi R.</td>
<td>2007</td>
<td>nd</td>
<td></td>
<td>Bluegill, Black crappie &amp; Pumpkinseed fillet</td>
<td>(Delinsky et al. 2010)</td>
<td></td>
</tr>
<tr>
<td>North America</td>
<td>USA, Georgia</td>
<td>2006</td>
<td>0.3</td>
<td>0.3</td>
<td>Shark soft tissue</td>
<td>(Kumar et al., 2009)</td>
<td></td>
</tr>
<tr>
<td>North America</td>
<td>USA, Georgia</td>
<td>2006</td>
<td>0.7</td>
<td>&lt;0.1 - 2.10</td>
<td>Shark liver</td>
<td>(Kumar et al., 2009)</td>
<td></td>
</tr>
<tr>
<td>North America</td>
<td>USA, Georgia</td>
<td>2006</td>
<td>0.4</td>
<td>&lt;0.1 - 0.80</td>
<td>Shark muscle</td>
<td>(Kumar et al., 2009)</td>
<td></td>
</tr>
<tr>
<td>North America</td>
<td>USA</td>
<td>2007</td>
<td>nd</td>
<td></td>
<td>7</td>
<td>Leatherback turtle plasma</td>
<td>(Keller et al., 2012)</td>
</tr>
<tr>
<td>North America</td>
<td>USA</td>
<td>2007</td>
<td>0.02 ± 0.04</td>
<td>&lt;0.01 - 0.13 (0.00)</td>
<td>15 (20 %)</td>
<td>Loggerhead turtle plasma</td>
<td>(Keller et al., 2012)</td>
</tr>
<tr>
<td>North America</td>
<td>USA</td>
<td>2007</td>
<td>0.02 ± 0.02</td>
<td>&lt;0.01 - 0.06 (0.02)</td>
<td>10 (30 %)</td>
<td>Kemp’s ridley turtle plasma</td>
<td>(Keller et al., 2012)</td>
</tr>
<tr>
<td>North America</td>
<td>USA</td>
<td>2007</td>
<td>0.04 ± 0.06</td>
<td>&lt;0.02 - 0.14 (0.01)</td>
<td>5 (40 %)</td>
<td>Hawksbill turtle plasma</td>
<td>(Keller et al., 2012)</td>
</tr>
<tr>
<td>North America</td>
<td>USA</td>
<td>2007</td>
<td>0.09 ± 0.27</td>
<td>&lt;0.02 - 0.85 (0.00)</td>
<td>10 (20 %)</td>
<td>Green turtle plasma</td>
<td>(Keller et al., 2012)</td>
</tr>
</tbody>
</table>
Figure 4. Environmental concentrations of PFBS in marine biota from other regions than the arctic (ng/g ww).
4.4.3.3 Freshwater

Measurements in freshwater biota were primarily from Taihu Lake, China (Fang et al. 2014) and a national survey of river basins in Vietnam (Lam et al. 2017). The highest concentration in Taihu Lake was associated with zooplankton (1.68 ng/g ww) and in Vietnam with Tilapia liver (1.34 ng/g ww).

Table 7. Environmental concentrations of PFBS in freshwater biota (ng/g ww). See Appendix A1 for Latin names.

<table>
<thead>
<tr>
<th>Region</th>
<th>Location</th>
<th>Date</th>
<th>Mean +/- SD</th>
<th>Maks</th>
<th>n</th>
<th>Remark</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asia</td>
<td>China, Taihu Lake</td>
<td>2012</td>
<td>nd</td>
<td></td>
<td></td>
<td>Phytoplankton</td>
<td>Fang et al. 2014</td>
</tr>
<tr>
<td>Asia</td>
<td>China, Taihu Lake</td>
<td>2012</td>
<td>nd</td>
<td></td>
<td></td>
<td>Crucian muscle</td>
<td>Fang et al. 2014</td>
</tr>
<tr>
<td>Asia</td>
<td>China, Taihu Lake</td>
<td>2012</td>
<td>0.08 ± 0.00</td>
<td>Lake saury muscle</td>
<td></td>
<td></td>
<td>Fang et al. 2014</td>
</tr>
<tr>
<td>Asia</td>
<td>China, Taihu Lake</td>
<td>2012</td>
<td>0.10 ± 0.00</td>
<td>Carp muscle</td>
<td></td>
<td></td>
<td>Fang et al. 2014</td>
</tr>
<tr>
<td>Asia</td>
<td>China, Taihu Lake</td>
<td>2012</td>
<td>0.54 ± 0.01</td>
<td>Mongolian culter muscle</td>
<td></td>
<td></td>
<td>Fang et al. 2014</td>
</tr>
<tr>
<td>Asia</td>
<td>China, Taihu Lake</td>
<td>2012</td>
<td>0.24 ± 0.01</td>
<td>Mudfish muscle</td>
<td></td>
<td></td>
<td>Fang et al. 2014</td>
</tr>
<tr>
<td>Asia</td>
<td>China, Taihu Lake</td>
<td>2012</td>
<td>nd</td>
<td>Chinese bitterling muscle</td>
<td></td>
<td></td>
<td>Fang et al. 2014</td>
</tr>
<tr>
<td>Asia</td>
<td>China, Taihu Lake</td>
<td>2012</td>
<td>nd</td>
<td>Gobiesmuscle</td>
<td></td>
<td></td>
<td>Fang et al. 2014</td>
</tr>
<tr>
<td>Asia</td>
<td>China, Taihu Lake</td>
<td>2012</td>
<td>1.68 ± 0.04</td>
<td>Zooplankton</td>
<td></td>
<td></td>
<td>Fang et al. 2014</td>
</tr>
<tr>
<td>Asia</td>
<td>China, Taihu Lake</td>
<td>2012</td>
<td>nd</td>
<td>Lake shrimp soft tissue</td>
<td></td>
<td></td>
<td>Fang et al. 2014</td>
</tr>
<tr>
<td>Asia</td>
<td>China, Taihu Lake</td>
<td>2012</td>
<td>nd</td>
<td>White shrimp soft tissue</td>
<td></td>
<td></td>
<td>Fang et al. 2014</td>
</tr>
<tr>
<td>Asia</td>
<td>China, Taihu Lake</td>
<td>2012</td>
<td>nd</td>
<td>Freshwater mussel soft tissue</td>
<td></td>
<td></td>
<td>Fang et al. 2014</td>
</tr>
<tr>
<td>Asia</td>
<td>China, Taihu Lake</td>
<td>2012</td>
<td>nd</td>
<td>Pearl mussel soft tissue</td>
<td></td>
<td></td>
<td>Fang et al. 2014</td>
</tr>
<tr>
<td>Asia</td>
<td>China, Taihu Lake</td>
<td>2012</td>
<td>nd</td>
<td>Minnow muscle</td>
<td></td>
<td></td>
<td>Fang et al. 2014</td>
</tr>
<tr>
<td>Asia</td>
<td>China, Taihu Lake</td>
<td>2012</td>
<td>nd</td>
<td>Silver carp muscle</td>
<td></td>
<td></td>
<td>Fang et al. 2014</td>
</tr>
<tr>
<td>Asia</td>
<td>China, Taihu Lake</td>
<td>2012</td>
<td>1.20 ± 0.03</td>
<td>Whitebait muscle</td>
<td></td>
<td></td>
<td>Fang et al. 2014</td>
</tr>
<tr>
<td>Asia</td>
<td>Vietman</td>
<td>2013-2015</td>
<td>0.11 ± 0.54</td>
<td>1.34</td>
<td>149</td>
<td>Fish and shellfish tissue (average of 5 fish species, 2 crustaceans (paddle crab, giant prawn), 1 gastropod (golden apple snail), 1 bivalve (golden freshwater clam)</td>
<td>Lam et al., 2017</td>
</tr>
</tbody>
</table>
Figure 5. Environmental concentrations of PFBS in freshwater biota (ng/g ww).
4.4.3.4 Plants

PFBS has shown a high propensity to transfer and enrich in plants, due to its high mobility in plant xylem. Most of the data on this are from plants grown in PFAS contaminated soil that was unintentionally impacted through fertilizer impurities (Kowalczyk et al., 2013) or from soil augmented intentionally with PFAS-contaminated biosolid-fertilizer (Blain et al., 2014). This data indicates that plants may reach levels as high as a 1 µg/g w (Kowalczyk et al., 2013). Hence, exposure to PFBS through plants grown in contaminated soil is an important pathway to consider in risk assessment regarding contaminated farmland.

Table 9. Environmental concentrations of PFBS in terrestrial plants (ng/g ww). See Appendix A1 for Latin names.

<table>
<thead>
<tr>
<th>Region</th>
<th>Location</th>
<th>Year</th>
<th>Mean +/- SD</th>
<th>Min-Maks (Median)</th>
<th>n (det. Freq)</th>
<th>Remark</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Europe</td>
<td>Germany</td>
<td>2013</td>
<td>68.40 ± 23.10</td>
<td>29.00 - 98.00</td>
<td>7</td>
<td>Grass silage (dw=0.41 ww)</td>
<td>(Kowalczyk et al., 2013)</td>
</tr>
<tr>
<td>Europe</td>
<td>Germany</td>
<td>2013</td>
<td>993.60 ± 224.40</td>
<td>843.00 - 1,419.00</td>
<td>7</td>
<td>Hay (dw=0.41 ww)</td>
<td>(Kowalczyk et al., 2013)</td>
</tr>
<tr>
<td>North America</td>
<td>USA, Greenhouse</td>
<td>2013</td>
<td>107.00 ± 29.18</td>
<td></td>
<td></td>
<td>Celery shoot industrial</td>
<td>(Blain et al., 2014)</td>
</tr>
<tr>
<td>North America</td>
<td>USA, Greenhouse</td>
<td>2013</td>
<td>164.20 ± 13.36</td>
<td></td>
<td></td>
<td>Radish root</td>
<td>(Blain et al., 2014)</td>
</tr>
<tr>
<td>North America</td>
<td>USA, Greenhouse</td>
<td>2013</td>
<td>34.40 ± 15.08</td>
<td></td>
<td></td>
<td>Tomato root</td>
<td>(Blain et al., 2014)</td>
</tr>
<tr>
<td>North America</td>
<td>USA, Greenhouse</td>
<td>2013</td>
<td>177.10 ± 21.78</td>
<td></td>
<td></td>
<td>Tomato shoot</td>
<td>(Blain et al., 2014)</td>
</tr>
<tr>
<td>North America</td>
<td>USA, Greenhouse</td>
<td>2013</td>
<td>43.00 ± 10.63</td>
<td></td>
<td></td>
<td>Pea root</td>
<td>(Blain et al., 2014)</td>
</tr>
<tr>
<td>North America</td>
<td>USA, Greenhouse</td>
<td>2013</td>
<td>200.10 ± 20.13</td>
<td></td>
<td></td>
<td>Pea shoot</td>
<td>(Blain et al., 2014)</td>
</tr>
<tr>
<td>North America</td>
<td>USA, Greenhouse</td>
<td>2013</td>
<td>4.50 ± 2.80</td>
<td></td>
<td></td>
<td>Celery shoot municipal</td>
<td>(Blain et al., 2014)</td>
</tr>
<tr>
<td>North America</td>
<td>USA, Greenhouse</td>
<td>2013</td>
<td>&lt;0.07</td>
<td></td>
<td></td>
<td>Pea fruit control</td>
<td>(Blain et al., 2014)</td>
</tr>
<tr>
<td>North America</td>
<td>USA, Greenhouse</td>
<td>2013</td>
<td>16.20 ± 2.55</td>
<td></td>
<td></td>
<td>Pea fruit industrial</td>
<td>(Blain et al., 2014)</td>
</tr>
<tr>
<td>North America</td>
<td>USA, Greenhouse</td>
<td>2013</td>
<td>&lt;0.07</td>
<td></td>
<td></td>
<td>Pea fruit municipal</td>
<td>(Blain et al., 2014)</td>
</tr>
<tr>
<td>North America</td>
<td>USA, Greenhouse</td>
<td>2013</td>
<td>22.40 ± 2.74</td>
<td></td>
<td></td>
<td>Radish root control</td>
<td>(Blain et al., 2014)</td>
</tr>
<tr>
<td>North America</td>
<td>USA, Greenhouse</td>
<td>2013</td>
<td>61.90 ± 19.35</td>
<td></td>
<td></td>
<td>Radish root industrial</td>
<td>(Blain et al., 2014)</td>
</tr>
<tr>
<td>North America</td>
<td>USA, Greenhouse</td>
<td>2013</td>
<td>23.90 ± 2.10</td>
<td></td>
<td></td>
<td>Radish root municipal</td>
<td>(Blain et al., 2014)</td>
</tr>
<tr>
<td>North America</td>
<td>USA, Greenhouse</td>
<td>2013</td>
<td>122.60 ± 23.86</td>
<td></td>
<td></td>
<td>Celery root</td>
<td>(Blain et al., 2014)</td>
</tr>
</tbody>
</table>
Figure 7. Environmental concentrations of PFBS in terrestrial plants (ng/g dw).
4.4.3.5 Terrestrial

Measurements in terrestrial biota were available from a study on cows eating contaminated hay grown mentioned in the previous section for 28 days, resulting in kidney mean 1.00 ± 0.30 ng/g ww (Kowalczyk et al., 2013). A Norwegian study on earthworms reported a mean of 0.75 ng/g ww (Miljødirektoratet, 2016).

Table 8. Environmental concentrations of PFBS in freshwater biota (ng/g ww). See Appendix A1 for Latin names.

<table>
<thead>
<tr>
<th>Region</th>
<th>Location</th>
<th>Date</th>
<th>Mean +/- SD</th>
<th>Min-Maks(Median)</th>
<th>n (det. Freq)</th>
<th>Remark</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Europe</td>
<td>Germany</td>
<td>2013</td>
<td>0.30 ± 0.30</td>
<td>3 (66 %)</td>
<td>0.30 ± 0.30</td>
<td>Cow liver (After 28 days feeding PFAS contaminated hay)</td>
<td>(Kowalczyk et al., 2013)</td>
</tr>
<tr>
<td>Europe</td>
<td>Germany</td>
<td>2013</td>
<td>1.00 ± 0.30</td>
<td>3 (100 %)</td>
<td>1.00 ± 0.30</td>
<td>Cow kidney (After 28 days feeding PFAS contaminated hay)</td>
<td>(Kowalczyk et al., 2013)</td>
</tr>
<tr>
<td>Europe</td>
<td>Germany</td>
<td>2013</td>
<td>nd</td>
<td>3</td>
<td>nd</td>
<td>Cow muscle tissue (After 28 days feeding PFAS contaminated hay)</td>
<td>(Kowalczyk et al., 2013)</td>
</tr>
<tr>
<td>Europe</td>
<td>Germany</td>
<td>2013</td>
<td>0.02 ± 0.04</td>
<td>3 (100 %)</td>
<td>0.02 ± 0.04</td>
<td>Cow milk (After 28 days feeding PFAS contaminated hay)</td>
<td>(Kowalczyk et al., 2013)</td>
</tr>
<tr>
<td>Europe</td>
<td>Norway</td>
<td>2015</td>
<td>0.75</td>
<td>0.13 - 1.10 (0.13)</td>
<td>6 (83 %)</td>
<td>Earthworms</td>
<td>(Miljødirektoratet, 2016)</td>
</tr>
</tbody>
</table>

Figure 6. Environmental concentrations of PFBS in terrestrial biota (ng/g ww).
PFBS has been reported in marine water throughout the world. Seven studies have detected PFBS in arctic marine water, with the highest value at 0.11 ng/L (Kallenborn et al., 2004). Two studies have reported PFBS in antarctic marine water, with a maximum at 0.10 ng/L (Cai et al., 2011). The highest European concentration were off the coast of Denmark at 1.09 ng/L (Kallenborn et al., 2004) and the highest in Asia was from the South China Sea both at 1.48 ng/L (Kwok et al., 2015).

Table 10. Environmental concentrations of PFBS in marine water samples (ng/L).

<table>
<thead>
<tr>
<th>Region</th>
<th>Location</th>
<th>Year</th>
<th>Mean +/- SD</th>
<th>Min-Maks (Median)</th>
<th>n (det. Freq)</th>
<th>Remark</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arctic</td>
<td>Arctic Ocean</td>
<td>2010</td>
<td>0.03 ± 0.03</td>
<td>&lt;0.017 - 0.08 (&lt;0.017)</td>
<td>13 (38 %)</td>
<td>(Cai et al., 2011)</td>
<td></td>
</tr>
<tr>
<td>Arctic</td>
<td>Central Arctic</td>
<td>2012</td>
<td>0.01 ± 0.01</td>
<td>0.04</td>
<td>(Yeung et al., 2017)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arctic</td>
<td>Faroe Islands</td>
<td>2004</td>
<td>0.05 - 0.11</td>
<td>(Kallenborn et al., 2004)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arctic</td>
<td>Iceland</td>
<td>2004</td>
<td>0.05 - 0.08</td>
<td>(Kallenborn et al., 2004)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arctic</td>
<td>North Atlantic</td>
<td>2009-2010</td>
<td>nd</td>
<td>0.045</td>
<td>62</td>
<td>(Zhao et al., 2012)</td>
<td></td>
</tr>
<tr>
<td>Arctic</td>
<td>Northwest Pacific Ocean</td>
<td>2010</td>
<td>0.02 ± 0.03</td>
<td>&lt;0.017 - 0.10 (&lt;0.017)</td>
<td>9 (33 %)</td>
<td>(Cai et al., 2011)</td>
<td></td>
</tr>
<tr>
<td>Arctic</td>
<td>Russian Arctic Baydaratskaya</td>
<td>2007</td>
<td>0.0132</td>
<td></td>
<td></td>
<td>(Saez et al., 2008)</td>
<td></td>
</tr>
<tr>
<td>Antarctic</td>
<td>Antarctica</td>
<td>2007</td>
<td>0.0029</td>
<td></td>
<td></td>
<td>(Wei et al., 2007)</td>
<td></td>
</tr>
<tr>
<td>Antarctic</td>
<td>South Atlantic</td>
<td>2009-2010</td>
<td>nd</td>
<td>nd-0.013</td>
<td>39</td>
<td>(Zhao et al., 2012)</td>
<td></td>
</tr>
<tr>
<td>International</td>
<td>Mid-Atlantic</td>
<td>2009-2010</td>
<td>nd</td>
<td>nd-0.017</td>
<td>20</td>
<td>(Zhao et al., 2012)</td>
<td></td>
</tr>
<tr>
<td>Europe</td>
<td>Baltic sea, Kattegat</td>
<td>2013</td>
<td>0.32</td>
<td>0.06 - 0.57</td>
<td>18 (65 %)</td>
<td>(Nguyen et al., 2017)</td>
<td></td>
</tr>
<tr>
<td>Europe</td>
<td>Denmark</td>
<td>2004</td>
<td>0.8</td>
<td>0.30 - 1.09</td>
<td>4</td>
<td>(Kallenborn et al., 2004)</td>
<td></td>
</tr>
<tr>
<td>Europe</td>
<td>Farao Islands</td>
<td>2004</td>
<td>0.1</td>
<td>0.05 - 0.20</td>
<td>4</td>
<td>(Kallenborn et al., 2004)</td>
<td></td>
</tr>
<tr>
<td>Europe</td>
<td>Finland</td>
<td>2004</td>
<td>0.07</td>
<td>&lt;LOQ - 0.93</td>
<td>3</td>
<td>(Kallenborn et al., 2004)</td>
<td></td>
</tr>
<tr>
<td>Europe</td>
<td>Iceland</td>
<td>2004</td>
<td>0.06</td>
<td>0.05 - 0.08</td>
<td>4</td>
<td>(Kallenborn et al., 2004)</td>
<td></td>
</tr>
<tr>
<td>Europe</td>
<td>Western Mediterranean Sea</td>
<td>2014</td>
<td>0.01 ± 0.01</td>
<td>nd - 0.02 (0.02)</td>
<td>0.012 (0 %)</td>
<td>(Brumovsky et al. 2016)</td>
<td></td>
</tr>
<tr>
<td>Asia</td>
<td>China</td>
<td>2013</td>
<td>0.66</td>
<td>0.32 - 1.46 (0.49)</td>
<td>(100 %)</td>
<td>(July) (Chen et al., 2016)</td>
<td></td>
</tr>
<tr>
<td>Asia</td>
<td>China</td>
<td>2013</td>
<td>nd</td>
<td>&lt;MLQ - 0.24 (&lt;MLQ)</td>
<td>(19 %)</td>
<td>(November) (Chen et al., 2016)</td>
<td></td>
</tr>
<tr>
<td>Asia</td>
<td>Pacific Ocean</td>
<td>2007</td>
<td>0.02 ± 0.00</td>
<td></td>
<td>19 (16 %)</td>
<td>(November) (Chen et al., 2016)</td>
<td></td>
</tr>
<tr>
<td>Asia</td>
<td>Pacific Ocean</td>
<td>2007</td>
<td>0.07 ± 0.01</td>
<td></td>
<td></td>
<td>(November) (Wei et al., 2007)</td>
<td></td>
</tr>
<tr>
<td>Asia</td>
<td>South China Sea</td>
<td>2012-2013</td>
<td>0.63 ± 0.43</td>
<td>0.25 - 1.48 (0.45)</td>
<td>17 (100 %)</td>
<td>(Kwok et al., 2015)</td>
<td></td>
</tr>
</tbody>
</table>
Figure 8. Environmental concentrations of PFBS in marine water samples (ng/L).
4.4.5 Fresh water

4.4.5.1 Arctic fresh water, snow and ice

PFBS has been frequently detected in fresh water, snow and ice samples throughout the Arctic and Antarctic. The largest concentration from this review was measured at 4.90 ng/L (Lescord et al., 2015), but this was considered to be due to pollution from a local airport. Elsewhere concentrations typically ranged between 0.02-0.2 ng/L, which is in the low end of the range observed for rain in non-Arctic areas (Section 4.4.1), though one sample from northern Sweden contained 2.15 ng/L (Codling et al., 2014).

Table 11. Environmental concentrations of PFBS in Arctic fresh water, snow and ice samples (ng/L).

<table>
<thead>
<tr>
<th>Region</th>
<th>Location</th>
<th>Year</th>
<th>Mean +/- SD</th>
<th>Min-Maks(Median)</th>
<th>n (det. Freq)</th>
<th>Remark</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arctic</td>
<td>Arctic Ocean (Snow/Ice)</td>
<td>2010</td>
<td>0.17 ± 0.42</td>
<td>&lt;0.017 - 1.50 (0.02)</td>
<td>12 (50 %)</td>
<td>Snow/Ice</td>
<td>(Cai et al., 2011)</td>
</tr>
<tr>
<td>Arctic</td>
<td>Canada</td>
<td>2007-2008</td>
<td></td>
<td>0.01 - 0.02</td>
<td>11</td>
<td></td>
<td>(Veillette et al., 2012)</td>
</tr>
<tr>
<td>Arctic</td>
<td>Canada</td>
<td>2010-2011</td>
<td>0.07 ± 0.01</td>
<td>5</td>
<td></td>
<td></td>
<td>(Lescord et al., 2015)</td>
</tr>
<tr>
<td>Arctic</td>
<td>Canada</td>
<td>2010-2011</td>
<td>4.90 ± 1.00</td>
<td>5</td>
<td></td>
<td>Lake (local pollution)</td>
<td>(Lescord et al., 2015)</td>
</tr>
<tr>
<td>Arctic</td>
<td>Greenland</td>
<td>2015</td>
<td>0.0068</td>
<td></td>
<td>11</td>
<td>Ice cap (19 cm = 2015)</td>
<td>(Pickard et al., 2018)</td>
</tr>
<tr>
<td>Arctic</td>
<td>Greenland</td>
<td>2015</td>
<td>0.0042</td>
<td></td>
<td>11</td>
<td>Ice cap (134 cm = 2013)</td>
<td>(Pickard et al., 2018)</td>
</tr>
<tr>
<td>Arctic</td>
<td>Northern Sweden</td>
<td>2009</td>
<td>0.099</td>
<td>nd - 2.16</td>
<td>24</td>
<td>Snow/Ice</td>
<td>(Codling et al., 2014)</td>
</tr>
<tr>
<td>Arctic</td>
<td>Svalbard</td>
<td>2015</td>
<td>0.023</td>
<td>23</td>
<td></td>
<td>Lake Linnévatnet,</td>
<td>(Skaar, 2016)</td>
</tr>
<tr>
<td>Arctic</td>
<td>Svalbard</td>
<td>2015</td>
<td>0.022</td>
<td></td>
<td>2</td>
<td>melt water</td>
<td>(Skaar, 2016)</td>
</tr>
<tr>
<td>Arctic</td>
<td>Svalbard</td>
<td>2015</td>
<td>0.022</td>
<td></td>
<td>2</td>
<td>River</td>
<td>(Skaar, 2016)</td>
</tr>
<tr>
<td>Arctic</td>
<td>Svalbard</td>
<td>2015</td>
<td>0.024</td>
<td></td>
<td>2</td>
<td>Snow/Ice</td>
<td>(Skaar, 2016)</td>
</tr>
<tr>
<td>Antarctic</td>
<td>Antarctica (Lake)</td>
<td>2011</td>
<td>0.038</td>
<td>4</td>
<td></td>
<td>Lake (King George Island)</td>
<td>(Cai et al., 2012)</td>
</tr>
<tr>
<td>Antarctic</td>
<td>Antarctica</td>
<td>2011</td>
<td>0.017</td>
<td>4</td>
<td></td>
<td>Snow/Ice (King George Island)</td>
<td>(Cai et al., 2012)</td>
</tr>
</tbody>
</table>
Figure 9. Environmental concentrations of PFBS in Arctic fresh water, snow and ice samples (ng/L). Note the logarithmic scale on the y-axis.
4.4.5.2 Surface fresh water near source zones

Surface water has been measured near PFAS production facilities in the Netherlands (Gebbink et al., 2017), China (Wang et al., 2016b), (Bao et al., 2010), (Zhou et al., 2013), electronic production facility wastewaters in Taiwan (Lin et al., 2014), Aqueous Film-Forming Foam (AFFF) contaminated areas in Canada, as well as mixed industrial areas that include fluorochemical plants in Italy (Valsecchi et al. (2015) and (Castiglioni et al. (2015)). The highest concentrations were found Tangxu Lake, near a PFAS production facility, where concentrations reached up to 5.3 µg/L (Zhou et al., 2013). In Europe the highest concentration was 1.7 µg/L from the Fratta Garzone river in Italy which receives water from textile industry and a fluorochemical plant (Valsecchi et al., 2015).

Table 12. Environmental concentrations of PFBS in surface water near PFAS production facilities or known hotspots (ng/L)

<table>
<thead>
<tr>
<th>Region</th>
<th>Location</th>
<th>Date</th>
<th>Mean +/- SD</th>
<th>Min-Maks(Median)</th>
<th>n (det. Freq)</th>
<th>Remark</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Europe</td>
<td>Italy (Bormida, Tanaro)</td>
<td>2010-2013</td>
<td>6.8 ± 5.5</td>
<td>&lt;LOD - 17.0 (5.9)</td>
<td>33 (80 %)</td>
<td>River basin survey</td>
<td>(Valsecchi et al., 2015)</td>
</tr>
<tr>
<td>Europe</td>
<td>Italy (Brenta, Fratta-Gorzone)</td>
<td>2010-2013</td>
<td>878.0 ± 764.0</td>
<td>56.0 - 1,665.7 (894.2)</td>
<td>4 (100 %)</td>
<td>River basin survey</td>
<td>(Valsecchi et al., 2015)</td>
</tr>
<tr>
<td>Europe</td>
<td>Italy</td>
<td>2010-2013</td>
<td>11 ± 0.0 - 66.0 (2.0)</td>
<td>(74 %)</td>
<td>Industrialized river</td>
<td>(Castiglioni et al., 2015)</td>
<td></td>
</tr>
<tr>
<td>Europe</td>
<td>Netherlands</td>
<td>2016</td>
<td>20.3 ± 3.7</td>
<td>12.0 - 27.0</td>
<td>18 (100 %)</td>
<td>River</td>
<td>(Gebbink et al., 2017)</td>
</tr>
<tr>
<td>Asia</td>
<td>China, Daling River</td>
<td>2014</td>
<td>1090</td>
<td>nd - 3,780.0 (668.0)</td>
<td>(74 %)</td>
<td>River</td>
<td>(Wang et al., 2016b)</td>
</tr>
<tr>
<td>Asia</td>
<td>China, Fuxin</td>
<td>2009</td>
<td>320</td>
<td>7.8 - 445.0 (353.0)</td>
<td>(42 %)</td>
<td>River</td>
<td>(Bao et al., 2010)</td>
</tr>
<tr>
<td>Asia</td>
<td>China, Tangxun Lake</td>
<td>2013</td>
<td>4950</td>
<td>4,600.0 - 5,300.0</td>
<td>2</td>
<td>WWTP</td>
<td>(Zhou et al., 2013)</td>
</tr>
<tr>
<td>Asia</td>
<td>China, Tangxun</td>
<td>2013</td>
<td>3720</td>
<td>2,240.0 - 4,520.0</td>
<td>(32 %)</td>
<td>Lake</td>
<td>(Zhou et al., 2013)</td>
</tr>
<tr>
<td>Asia</td>
<td>Taiwan</td>
<td>2013</td>
<td>0.3 ± 0.2</td>
<td>(29 %)</td>
<td>Upstream WWTP</td>
<td>(Lin et al., 2014)</td>
<td></td>
</tr>
<tr>
<td>Asia</td>
<td>Taiwan</td>
<td>2013</td>
<td>329.0 ± 16.0</td>
<td>(33 %)</td>
<td>WWTP</td>
<td>(Lin et al., 2014)</td>
<td></td>
</tr>
<tr>
<td>Asia</td>
<td>Taiwan</td>
<td>2013</td>
<td>392.0 ± 6.0</td>
<td>(37 %)</td>
<td>Downstream WWTP</td>
<td>(Lin et al., 2014)</td>
<td></td>
</tr>
<tr>
<td>Asia</td>
<td>Taiwan</td>
<td>2013</td>
<td>282.0 ± 9.0</td>
<td>(35 %)</td>
<td>Downstream WWTP</td>
<td>(Lin et al., 2014)</td>
<td></td>
</tr>
<tr>
<td>Asia</td>
<td>Taiwan</td>
<td>2013</td>
<td>262.0 ± 4.4</td>
<td>(36 %)</td>
<td>Downstream WWTP</td>
<td>(Lin et al., 2014)</td>
<td></td>
</tr>
<tr>
<td>North America</td>
<td>Canada</td>
<td>2012-2016</td>
<td>6.4 ± 4.5</td>
<td>0.8 - 13.0 (4.4)</td>
<td>14 (100 %)</td>
<td>AFFF source</td>
<td>(D’Agostino and Mabury et al., 2017)</td>
</tr>
</tbody>
</table>
Figure 10: Environmental concentrations of PFBS in surface water near PFAS production facilities or known hotspots (ng/L)
4.4.5.3 Surface fresh water (excluding Arctic and near source zones)

Most PFBS data in the peer-reviewed literature is for surface fresh water. It has been found in surface fresh waters throughout Europe, Asia and North America, where it has been reported over a wide range of concentrations. The highest PFBS concentration of 1450 ng/L, reported in the Möhne river in Germany (Skutlarek et al., 2006), was attributed to the use of contaminated fertilizer in an agricultural area. The ubiquity of PFBS in water samples shows that it is highly mobile and well distributed in the freshwater environment, even apart from source zones.

Table 13. Environmental concentrations of PFBS in surface fresh water samples (ng/L).

<table>
<thead>
<tr>
<th>Region</th>
<th>Location</th>
<th>Date</th>
<th>Mean +/- SD</th>
<th>Min-Maks(Median)</th>
<th>n (det. Freq)</th>
<th>Remark</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Europe</td>
<td>Baltic sea</td>
<td>2013-2014</td>
<td>0.10 ± 0.00</td>
<td></td>
<td>(100 %)</td>
<td></td>
<td>Gebbink et al., 2016a</td>
</tr>
<tr>
<td>Europe</td>
<td>Elbe River</td>
<td>2014</td>
<td>2.3</td>
<td>0.80 - 3.60 (2.40)</td>
<td>(100 %)</td>
<td></td>
<td>Heydebreck et al. 2015</td>
</tr>
<tr>
<td>Europe</td>
<td>France</td>
<td>2009</td>
<td>5</td>
<td></td>
<td>(1 %)</td>
<td></td>
<td>Boiteaux et al., 2012</td>
</tr>
<tr>
<td>Europe</td>
<td>France</td>
<td>2012</td>
<td>&lt;0.02 - 29.00</td>
<td>(65 %)</td>
<td></td>
<td></td>
<td>Munos et al., 2015</td>
</tr>
<tr>
<td>Europe</td>
<td>Germany Bad Godesberg</td>
<td>2008-2009</td>
<td>&lt;0.01</td>
<td>&lt;0.01 - 0.00 (&lt;0.01)</td>
<td></td>
<td></td>
<td>Wilhelm et al., 2010</td>
</tr>
<tr>
<td>Europe</td>
<td>Germany Bimmen-Lobith</td>
<td>2008-2009</td>
<td>0.00 - 0.08 (0.02)</td>
<td></td>
<td>(89 %)</td>
<td></td>
<td>Wilhelm et al., 2010</td>
</tr>
<tr>
<td>Europe</td>
<td>Germany Düsseldorf-Flehe</td>
<td>2008-2009</td>
<td>0.00 - 0.10 (0.03)</td>
<td></td>
<td>(91 %)</td>
<td></td>
<td>Wilhelm et al., 2010</td>
</tr>
<tr>
<td>Europe</td>
<td>Germany Moehne river</td>
<td>2008-2009</td>
<td>0.02 - 0.03 (0.02)</td>
<td></td>
<td>35 (100 %)</td>
<td></td>
<td>Wilhelm et al., 2010</td>
</tr>
<tr>
<td>Europe</td>
<td>Germany Ruhr River 0-100 km</td>
<td>2008-2009</td>
<td>0.023</td>
<td>0.00 - 0.09 (0.02)</td>
<td>(11 %)</td>
<td></td>
<td>Wilhelm et al., 2010</td>
</tr>
<tr>
<td>Europe</td>
<td>Germany Ruhr River 100-200 km</td>
<td>2008-2009</td>
<td>0.01</td>
<td>&lt;0.01 - 0.02 (&lt;0.01)</td>
<td>(81 %)</td>
<td></td>
<td>Wilhelm et al., 2010</td>
</tr>
<tr>
<td>Europe</td>
<td>Germany WkSt Rhein-Nord Kleeve</td>
<td>2008-2009</td>
<td>0.00 - 0.06 (0.03)</td>
<td></td>
<td>(92 %)</td>
<td></td>
<td>Wilhelm et al., 2010</td>
</tr>
<tr>
<td>Europe</td>
<td>Germany WkSt Süd/Bad Honnef</td>
<td>2008-2009</td>
<td>&lt;0.01</td>
<td>&lt;0.01 - 0.03 (&lt;0.01)</td>
<td>(7 %)</td>
<td></td>
<td>Wilhelm et al., 2010</td>
</tr>
<tr>
<td>Europe</td>
<td>Germany, Moehne river</td>
<td>2006</td>
<td>319</td>
<td>&lt;LOD - 1,450 (83)</td>
<td>12</td>
<td></td>
<td>Skutlarek et al., 2006</td>
</tr>
<tr>
<td>Region</td>
<td>Location</td>
<td>Date</td>
<td>Mean +/- SD</td>
<td>Min-Maks(Median)</td>
<td>n (det. Freq)</td>
<td>Remark</td>
<td>Reference</td>
</tr>
<tr>
<td>------------------------</td>
<td>-----------------------------------------------</td>
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<td>--------------</td>
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<td>--------------------------------</td>
</tr>
<tr>
<td>Europe</td>
<td>Germany, Rhine river</td>
<td>2006</td>
<td>14.3</td>
<td>&lt;LOD - 46.00 (12.50)</td>
<td>38</td>
<td></td>
<td>(Skutlarek et al., 2006)</td>
</tr>
<tr>
<td>Europe</td>
<td>Germany, Rhine River</td>
<td>2016</td>
<td>21.9</td>
<td>0.46 - 146.00</td>
<td>20 (100 %)</td>
<td></td>
<td>(Pan et al., 2018)</td>
</tr>
<tr>
<td>Europe</td>
<td>Germany, Rhine watershed</td>
<td>2008</td>
<td>&lt;0.08 - 181.00</td>
<td></td>
<td></td>
<td></td>
<td>(Möller et al., 2010)</td>
</tr>
<tr>
<td>Europe</td>
<td>Germany, Ruhr river</td>
<td>2006</td>
<td>16.7</td>
<td>&lt;LOD - 71.00 (13.00)</td>
<td>27</td>
<td></td>
<td>(Skutlarek et al., 2006)</td>
</tr>
<tr>
<td>Europe</td>
<td>Germany</td>
<td>2007</td>
<td>6.3</td>
<td>3.40 - 17.70 (5.40)</td>
<td></td>
<td></td>
<td>(Ahrens et al., 2009a)</td>
</tr>
<tr>
<td>Europe</td>
<td>Italy (river basin survey)</td>
<td>2010-2013</td>
<td>8.90 ± 8.90</td>
<td>&lt;LOD - 31.40 (5.60)</td>
<td>104 (74 %)</td>
<td></td>
<td>(Valsecchi et al., 2015)</td>
</tr>
<tr>
<td>Europe</td>
<td>North Sea, Baltic Sea and Norwegian Sea</td>
<td>2009</td>
<td>6.51</td>
<td></td>
<td></td>
<td></td>
<td>(Ahrens et al., 2010)</td>
</tr>
<tr>
<td>Europe</td>
<td>Norway</td>
<td>2004</td>
<td>nd</td>
<td></td>
<td>5</td>
<td>Lake</td>
<td>(Kallenborn et al., 2004)</td>
</tr>
<tr>
<td>Europe</td>
<td>Norway</td>
<td>2004</td>
<td>42.8</td>
<td>5.64 - 112.00</td>
<td>6</td>
<td>Lake</td>
<td>(Kallenborn et al., 2004)</td>
</tr>
<tr>
<td>Europe</td>
<td>Rhine River</td>
<td>2013</td>
<td>15.6</td>
<td>1.40 - 40.00 (15.00)</td>
<td></td>
<td>(100 %)</td>
<td>(Heydebreck et al. 2015)</td>
</tr>
<tr>
<td>Europe</td>
<td>Spain</td>
<td>2009</td>
<td>1.22 ± 1.55</td>
<td>n.d. - 5.50</td>
<td>12 (17 %)</td>
<td></td>
<td>(Pico et al., 2012)</td>
</tr>
<tr>
<td>Europe</td>
<td>Spain</td>
<td>2009</td>
<td>1.33 ± 3.01</td>
<td>&lt;0.10 - 10.10 (0.20)</td>
<td>30 (57 %)</td>
<td></td>
<td>(Domingo et al., 2012)</td>
</tr>
<tr>
<td>Europe</td>
<td>SW along River Elbe</td>
<td>2007</td>
<td>2.2</td>
<td>0.00 - 3.40 (2.30)</td>
<td>30 (100 %)</td>
<td></td>
<td>(Ahrens et al., 2009b)</td>
</tr>
<tr>
<td>Europe</td>
<td>Sweden, Mälaren Lake</td>
<td>2016</td>
<td>1.43</td>
<td>0.75 - 1.92</td>
<td>10 (100 %)</td>
<td></td>
<td>(Pan et al., 2018)</td>
</tr>
<tr>
<td>Europe</td>
<td>Sweden</td>
<td>2015</td>
<td>0.24 ± 0.10</td>
<td>0.11 - 0.35 (0.23)</td>
<td>4 (100 %)</td>
<td>River</td>
<td>(Tröger et al., 2018)</td>
</tr>
<tr>
<td>Europe</td>
<td>Swedish rivers</td>
<td>2015</td>
<td>0.54 ± 0.46</td>
<td>0.19 - 1.20 (0.39)</td>
<td>2 (100 %)</td>
<td>Lake</td>
<td>(Tröger et al., 2018)</td>
</tr>
<tr>
<td>Europe</td>
<td>Switzerland, Glatt river</td>
<td>2007</td>
<td>4.3</td>
<td>2.30 - 7.70 (2.80)</td>
<td>3</td>
<td></td>
<td>(Huset et al., 2008)</td>
</tr>
<tr>
<td>Europe</td>
<td>UK, Thames River</td>
<td>2016</td>
<td>5.06</td>
<td>3.26 - 6.75</td>
<td>6 (100 %)</td>
<td></td>
<td>(Pan et al., 2018)</td>
</tr>
<tr>
<td>Europe</td>
<td>Xiaoqing River</td>
<td>2014</td>
<td>nd</td>
<td></td>
<td></td>
<td></td>
<td>(Heydebreck et al. 2015)</td>
</tr>
<tr>
<td>Asia</td>
<td>China, Chao Lake</td>
<td>2016</td>
<td>15.4</td>
<td>1.50 - 81.50</td>
<td>13 (100 %)</td>
<td></td>
<td>(Pan et al., 2018)</td>
</tr>
<tr>
<td>Asia</td>
<td>China, Huai River</td>
<td>2016</td>
<td>0.83</td>
<td>0.52 - 1.59</td>
<td>9 (100 %)</td>
<td></td>
<td>(Pan et al., 2018)</td>
</tr>
<tr>
<td>Asia</td>
<td>China, Liao River</td>
<td>2016</td>
<td>0.94</td>
<td>0.43 - 2.16</td>
<td>6 (100 %)</td>
<td></td>
<td>(Pan et al., 2018)</td>
</tr>
<tr>
<td>Region</td>
<td>Location</td>
<td>Date</td>
<td>Mean +/- SD</td>
<td>Min-Maks(Median)</td>
<td>n (det. Freq)</td>
<td>Remark</td>
<td>Reference</td>
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</tr>
<tr>
<td>Asia</td>
<td>China, Pearl River</td>
<td>2016</td>
<td>4.49</td>
<td>0.21 - 21.50</td>
<td>13 (100 %)</td>
<td></td>
<td>(Pan et al., 2018)</td>
</tr>
<tr>
<td>Asia</td>
<td>China, Shuangtaizi Estuary</td>
<td>2013</td>
<td>4.7</td>
<td>0.95 - 12.60 (4.45)</td>
<td>21 (100 %)</td>
<td></td>
<td>(Shao et al., 2006)</td>
</tr>
<tr>
<td>Asia</td>
<td>China, Tai Lake</td>
<td>2016</td>
<td>2.02</td>
<td>0.17 - 4.85</td>
<td>15 (100 %)</td>
<td></td>
<td>(Pan et al., 2018)</td>
</tr>
<tr>
<td>Asia</td>
<td>China, Taihu Lake</td>
<td>2012</td>
<td>3.76 ± 0.72</td>
<td></td>
<td></td>
<td></td>
<td>(Fang et al. 2014)</td>
</tr>
<tr>
<td>Asia</td>
<td>China, Yangtze River</td>
<td>2016</td>
<td>1.84</td>
<td>0.22 - 4.68</td>
<td>35 (100 %)</td>
<td></td>
<td>(Pan et al., 2018)</td>
</tr>
<tr>
<td>Asia</td>
<td>China, Yellow River</td>
<td>2016</td>
<td>0.99</td>
<td>0.07 - 2.23</td>
<td>15 (100 %)</td>
<td></td>
<td>(Pan et al., 2018)</td>
</tr>
<tr>
<td>Asia</td>
<td>Hong Kong</td>
<td>2008-2010</td>
<td>6.83 ± 2.40</td>
<td>2.18 - 8.69 (7.30)</td>
<td>12 (100 %)</td>
<td></td>
<td>(Loi et al., 2011)</td>
</tr>
<tr>
<td>Asia</td>
<td>Korea, Han River</td>
<td>2016</td>
<td>2.27</td>
<td>1.34 - 3.17</td>
<td>6 (100 %)</td>
<td></td>
<td>(Pan et al., 2018)</td>
</tr>
<tr>
<td>Asia</td>
<td>South Korea, Shihwa Industrial zone</td>
<td>2004</td>
<td>2.5</td>
<td>4.27</td>
<td></td>
<td></td>
<td>(Rostkowski et al., 2006)</td>
</tr>
<tr>
<td>Asia</td>
<td>Vietnam</td>
<td>2013-2015</td>
<td>0.10 - 8.28 (4.19)</td>
<td></td>
<td>5 (100 %)</td>
<td>Urban</td>
<td>(Lam et al., 2017)</td>
</tr>
<tr>
<td>North America</td>
<td>Canada</td>
<td>2012-2016</td>
<td>2.52 ± 1.04</td>
<td>1.40 - 4.00 (2.50)</td>
<td>5 (100 %)</td>
<td>Urban</td>
<td>(D'Agostino and Mabury et al., 2017)</td>
</tr>
<tr>
<td>North America</td>
<td>Canada</td>
<td>2012-2016</td>
<td>0.78 ± 0.90</td>
<td>0.00 - 1.70 (0.70)</td>
<td>4 (50 %)</td>
<td>Rural</td>
<td>(D’Agostino and Mabury et al., 2017)</td>
</tr>
<tr>
<td>North America</td>
<td>NJ, Delaware River</td>
<td>2016</td>
<td>2.19</td>
<td>0.52 - 4.20</td>
<td>12 (100 %)</td>
<td></td>
<td>(Pan et al., 2018)</td>
</tr>
</tbody>
</table>
Figure 11. Environmental concentrations of PFBS in surface fresh water samples in non-Arctic areas (ng/L).
Groundwater data was available near two PFAS production facilities in China (Wang et al., 2018; Bao et al. 2010). Both were substantially contaminated with PFBS (max 870 ng/L). Away from PFAS sources, there is currently little data available. A European survey from 2008 found PFBS in 15% of samples, with max 25 ng/L and mean 0.3 ng/L (Loos et al., 2010). A French study found up to 9 ng/L, but it was only in 4% of tested samples (Boiteaux et al., 2012). A Vietnam GW survey did not find PFBS (Lam et al., 2017).

Table 14. Environmental concentrations of PFBS in groundwater (ng/L)

<table>
<thead>
<tr>
<th>Region</th>
<th>Location</th>
<th>Date</th>
<th>Mean +/- SD</th>
<th>Min-Maks (Median)</th>
<th>n (det. Freq)</th>
<th>Remark</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Europe</td>
<td>Europe - 26 countries</td>
<td>2008</td>
<td>0.3</td>
<td>25</td>
<td>164 (15 %)</td>
<td>GW</td>
<td>(Loos et al., 2010)</td>
</tr>
<tr>
<td>Europe</td>
<td>France</td>
<td>2009</td>
<td>9</td>
<td></td>
<td>(4 %)</td>
<td>GW</td>
<td>(Boiteaux et al., 2012)</td>
</tr>
<tr>
<td>Asia</td>
<td>Vietman</td>
<td>2013-2015</td>
<td>&lt;0.3</td>
<td></td>
<td></td>
<td>GW</td>
<td>(Lam et al., 2017)</td>
</tr>
<tr>
<td>Asia</td>
<td>China, Daling River</td>
<td>2014</td>
<td>375</td>
<td>865</td>
<td>4</td>
<td>Source zone: GW</td>
<td>(Wang et al., 2016b)</td>
</tr>
<tr>
<td>Asia</td>
<td>China, Fuxin</td>
<td>2009</td>
<td>235</td>
<td>1.2 - 872.0 (34.4)</td>
<td></td>
<td>Source zone: GW</td>
<td>(Bao et al., 2010)</td>
</tr>
</tbody>
</table>

Figure 12. Environmental concentrations of PFBS in groundwater (ng/L)
Drinking water samples, including finished water, bottled water, and treatment steps, have been analysed for PFBS in areas near and far removed from PFAS source zones. PFBS appears ubiquitous in drinking water, both from the tap and from bottles. In regions away from established PFAS source areas, substantial drinking water contamination can occur, with a France max of 15 ng/L (Schwanz et al., 2016), German max of 26 ng/L (Wilhelm et al., 2010), Italy max of 45 ng/L (IRSA-CNR, 2013), Spain max of 69 ng/L (Ericson et al., 2009), China max of 18 ng/L (Mak et al., 2009), and Brazil max of 16 ng/L (Schwanz et al., 2016). These concentrations even exceed those of some known source zones, such as 19.0 ng/L near a PFAS production facility in the Netherlands (Gebbink et al., 2017), and 0.6 ng/L for drinking water near the PFAS production area of Fuxin, China (Bao et al., 2010). The highest concentration, however, was near a source zone, at 97.8 ng/L, along the Daling River, China (Wang et al., 2016b). This indicates that PFBS, like other PFAS, persists through drinking water production, and therefore currently is ubiquitously present in global drinking water (Kaboré et al., 2018).

### Table 15. Environmental concentrations of PFBS in drinking water (ng/L)

<table>
<thead>
<tr>
<th>Region</th>
<th>Location</th>
<th>Date</th>
<th>Mean +/- SD</th>
<th>Min-Maks(Median)</th>
<th>n (det. Freq)</th>
<th>Remark</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>International</td>
<td>Global</td>
<td>2015</td>
<td>0.1</td>
<td>1.6</td>
<td>38 (47 %)</td>
<td>Bottled water (Canada, Burkina Faso, Chile, Ivory Coast, France, Japan, Mexico, Norway, USA)</td>
<td>(Kaboré et al., 2018)</td>
</tr>
<tr>
<td>International</td>
<td>Global</td>
<td>2015</td>
<td>0.24</td>
<td>0.0 - 1.1 (0.2)</td>
<td>59 (88 %)</td>
<td>Tap water (Canada, Burkina Faso, Chile, Ivory Coast, France, Japan, Mexico, Norway, USA)</td>
<td>(Kaboré et al., 2018)</td>
</tr>
<tr>
<td>Europe</td>
<td>France</td>
<td>2015</td>
<td>3.2</td>
<td>1.3 - 6.7 (2.9)</td>
<td>(32 %)</td>
<td>Bottled water</td>
<td>(Schwanz et al., 2016)</td>
</tr>
<tr>
<td>Europe</td>
<td>France</td>
<td>2015</td>
<td>6.8</td>
<td>2.0 - 15.0 (6.5)</td>
<td>(62 %)</td>
<td>Drinking water</td>
<td>(Schwanz et al., 2016)</td>
</tr>
<tr>
<td>Europe</td>
<td>Germany</td>
<td>2008-2009</td>
<td>&lt;0.01 - 0.0 (&lt;0.01)</td>
<td>70 (3 %)</td>
<td>Drinking water</td>
<td>(Wilhelm et al., 2010)</td>
<td></td>
</tr>
<tr>
<td>Europe</td>
<td>Germany, Ruhr river</td>
<td>2006</td>
<td>12.2</td>
<td>&lt;LOD - 26.0 (13.5)</td>
<td>37</td>
<td>Drinking water</td>
<td>(Skutlarek et al., 2006)</td>
</tr>
<tr>
<td>Europe</td>
<td>Italy</td>
<td>2010-2012</td>
<td>6.7 ± 11.3</td>
<td>&lt;0.5 - 45.0 (1.8)</td>
<td>46 (63 %)</td>
<td>Drinking water</td>
<td>(IRSA-CNR, 2013)</td>
</tr>
<tr>
<td>Europe</td>
<td>Netherlands</td>
<td>2008</td>
<td>24.0 ± 10.0</td>
<td>10.0 - 47.0</td>
<td>6</td>
<td>Infiltrated river water</td>
<td>(Eschauzier et al., 2010)</td>
</tr>
<tr>
<td>Region</td>
<td>Location</td>
<td>Date</td>
<td>Mean +/- SD</td>
<td>Min-Maks(Median)</td>
<td>n (det. Freq)</td>
<td>Remark</td>
<td>Reference</td>
</tr>
<tr>
<td>--------</td>
<td>----------</td>
<td>------------</td>
<td>-------------</td>
<td>-----------------</td>
<td>---------------</td>
<td>---------------------------------------------</td>
<td>--------------------------------</td>
</tr>
<tr>
<td>Europe</td>
<td>Netherlands</td>
<td>2008</td>
<td>2.4 ± 4.9</td>
<td>0.5 - 18.0</td>
<td>6</td>
<td>Infiltrated rainwater</td>
<td>(Eschauzier et al., 2010)</td>
</tr>
<tr>
<td>Europe</td>
<td>Spain</td>
<td>2009</td>
<td>4.5 ± 14.5</td>
<td>&lt;0.07 - 69.4 (0.4)</td>
<td></td>
<td>Drinking water</td>
<td>(Ericson et al., 2009)</td>
</tr>
<tr>
<td>Europe</td>
<td>Spain</td>
<td>2015</td>
<td>nd</td>
<td></td>
<td></td>
<td>Bottled water</td>
<td>(Schwanz et al., 2016)</td>
</tr>
<tr>
<td>Europe</td>
<td>Spain</td>
<td>2015</td>
<td>11</td>
<td>2.8 - 24.0 (11.0)</td>
<td>(31 %)</td>
<td>Drinking water</td>
<td>(Schwanz et al., 2016)</td>
</tr>
<tr>
<td>Europe</td>
<td>Sweden</td>
<td>2015</td>
<td>0.8 ± 0.3</td>
<td>0.3 - 1.3 (0.7)</td>
<td>11 (92 %)</td>
<td>Various parts of DW treatment production</td>
<td>(Tröger et al., 2018)</td>
</tr>
<tr>
<td>Asia</td>
<td>China, Shuangtaizi Estuary</td>
<td>2013</td>
<td>5.42</td>
<td>1.0 - 13.8 (4.4)</td>
<td>21 (100 %)</td>
<td>Bottled water</td>
<td>(Shao et al., 2006)</td>
</tr>
<tr>
<td>Asia</td>
<td>China</td>
<td>2008-2010</td>
<td></td>
<td>0.0 - 18.0 (2.8)</td>
<td>70 (74 %)</td>
<td>Drinking water</td>
<td>(Mak et al., 2009)</td>
</tr>
<tr>
<td>North America</td>
<td>New Jersey</td>
<td>2009-2010</td>
<td>nd</td>
<td>6</td>
<td>30 (10 %)</td>
<td>Raw water</td>
<td>(Post et al., 2013)</td>
</tr>
<tr>
<td>South America</td>
<td>Brazil</td>
<td>2015</td>
<td>3.4</td>
<td>3.1 - 3.6 (3.5)</td>
<td>(50 %)</td>
<td>Bottled water</td>
<td>(Schwanz et al., 2016)</td>
</tr>
<tr>
<td>South America</td>
<td>Brazil</td>
<td>2015</td>
<td>4.4</td>
<td>0.5 - 16.0 (1.3)</td>
<td>(90 %)</td>
<td>Drinking water</td>
<td>(Schwanz et al., 2016)</td>
</tr>
<tr>
<td>Europe</td>
<td>Netherlands</td>
<td>2016</td>
<td>4.94</td>
<td>0.5 - 19.0</td>
<td>6 (100 %)</td>
<td>Source zone: Drinking water</td>
<td>(Gebbink et al., 2017)</td>
</tr>
<tr>
<td>Asia</td>
<td>China, Daling River</td>
<td>2014</td>
<td>25.4</td>
<td>97.8</td>
<td>4</td>
<td>Source zone: Drinking water</td>
<td>(Wang et al., 2016b)</td>
</tr>
<tr>
<td>Asia</td>
<td>China, Fuxin</td>
<td>2009</td>
<td>0.47</td>
<td>0.2 - 0.7 (0.5)</td>
<td></td>
<td>Source zone: Raw water</td>
<td>(Bao et al., 2010)</td>
</tr>
<tr>
<td>Asia</td>
<td>China, Fuxin</td>
<td>2009</td>
<td>0.54</td>
<td>&lt;0.1 - 0.6 (0.5)</td>
<td></td>
<td>Source zone: Finished water</td>
<td>(Bao et al., 2010)</td>
</tr>
<tr>
<td>Asia</td>
<td>China, Fuxin</td>
<td>2009</td>
<td>0.54</td>
<td>&lt;0.1 - 0.6 (0.5)</td>
<td></td>
<td>Source zone: Drinking water</td>
<td>(Bao et al., 2010)</td>
</tr>
</tbody>
</table>
Figure 13: Environmental concentrations of PFBS in drinking water (ng/L)
4.4.6 Soil and Sediments

Only one study of PFBS in soil could be found, which reported only 10% frequency of detection and a max of 0.003 ng/g dw (Miljødirektoratet, 2016). A study on Arctic sediments in 2003, however, was able to quantify PFBS in surface sediments, at a max of 0.1 ng/g dw, which is an indicator of long range transport. There is in general a lack of soil and sediment data. Based on the log Koc of 2.2 (units L/kg organic carbon Table 1), it would be anticipated under equilibrium conditions that the concentrations in soil/sediment with 1% organic carbon in ng/g would be 0.16% of water concentrations in ng/L (c_{sediment} (ng/g) = Koc*c_{water}*0.01*organic carbon*0.001kg/g = 0.0016 c_{water} (ng/L)).

Table 17. Environmental concentrations of PFBS in soil and sediment samples (ng/g dw)

<table>
<thead>
<tr>
<th>Region</th>
<th>Location</th>
<th>Date</th>
<th>Mean +/- SD</th>
<th>Min-Maks(Median)</th>
<th>n (det. Freq)</th>
<th>Remark</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arctic</td>
<td>Canada Resolute Lake</td>
<td>2003</td>
<td>&lt;1.1</td>
<td>nd - 0.1</td>
<td>(75 %)</td>
<td>0-3 cm cores</td>
<td>(Stock et al., 2007)</td>
</tr>
<tr>
<td>Arctic</td>
<td>Canada Char Lake</td>
<td>2003</td>
<td>0.0002 ± 0.0001</td>
<td>&lt;LOD - 0.003 (&lt;LOD)</td>
<td>10 (10 %)</td>
<td>0-3 cm cores</td>
<td>(Gebbink et al., 2016a)</td>
</tr>
<tr>
<td>Arctic</td>
<td>Canada Amituk Lake</td>
<td>2003</td>
<td>0.0 - 0.1</td>
<td>0.0 - 0.1</td>
<td>(100 %)</td>
<td>0-3 cm cores</td>
<td>(Gebbink et al., 2016a)</td>
</tr>
<tr>
<td>Europe</td>
<td>Baltic sea (sediment)</td>
<td>2013-2014</td>
<td>0.06</td>
<td>0.0 - 0.2 (0.1)</td>
<td>(100 %)</td>
<td>Surface sediments (July)</td>
<td>(Miljødirektoratet, 2016)</td>
</tr>
<tr>
<td>Europe</td>
<td>Norway (soil)</td>
<td>2015</td>
<td>&lt;LOD</td>
<td>&lt;LOD - 0.003 (&lt;LOD)</td>
<td>(100 %)</td>
<td>Surface sediments (October)</td>
<td>(Chen et al., 2016)</td>
</tr>
<tr>
<td>Asia</td>
<td>China (sediment)</td>
<td>2013</td>
<td>0.06</td>
<td>0.1 - 0.1 (0.1)</td>
<td>(100 %)</td>
<td>Urban</td>
<td>(Chen et al., 2016)</td>
</tr>
<tr>
<td>Asia</td>
<td>China (sediment)</td>
<td>2013</td>
<td>0.06</td>
<td>0.1 - 0.1 (0.1)</td>
<td>(100 %)</td>
<td>Urban</td>
<td>(Chen et al., 2016)</td>
</tr>
<tr>
<td>Asia</td>
<td>Hong Kong (sediment)</td>
<td>2008-2010</td>
<td>0.026</td>
<td>&lt;0.026</td>
<td></td>
<td>Urban</td>
<td>(Chen et al., 2016)</td>
</tr>
<tr>
<td>North America</td>
<td>Canada (sediment)</td>
<td>2012-2016</td>
<td>nd</td>
<td></td>
<td></td>
<td></td>
<td>(D'Agostino and Mabury et al., 2017)</td>
</tr>
</tbody>
</table>
Figure 15. Environmental concentrations of PFBS in soil and sediment samples (ng/g dw)
4.4.7 Waste Water and Leachate

PFBS is also commonly found in WWTP and Leachate effluent. In general, concentrations in landfill effluent are higher, with a max of 3410 ng/L, (Lang et al. 2017), compared to the maximum identified WWTP effluent sample of 26 ng/L (Ahrens et al., 2009b). This indicates that landfills can be environmental hotspots for PFBS emissions. By comparison, the highest concentration in surface water near a PFAS production facility was 5300 ng/L (Zhou et al., 2013).

Table 18. Environmental concentrations of PFBS in waste water and leachate samples (ng/L)

<table>
<thead>
<tr>
<th>Region</th>
<th>Location</th>
<th>Date</th>
<th>Mean +/- SD</th>
<th>Min-Maks(Median)</th>
<th>n (det. Freq)</th>
<th>Remark</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arctic</td>
<td>Faroe Islands</td>
<td>2004</td>
<td>0.2</td>
<td>&lt;LOQ - 68.00</td>
<td>3</td>
<td>WWTP</td>
<td>(Kallenborn et al., 2004)</td>
</tr>
<tr>
<td>Europe</td>
<td>Finland</td>
<td>2004</td>
<td>64.6</td>
<td>2.61 - 3.09</td>
<td>3</td>
<td>Landfill</td>
<td>(Kallenborn et al., 2004)</td>
</tr>
<tr>
<td>Europe</td>
<td>Finland</td>
<td>2004</td>
<td>2.9</td>
<td>2.61 - 3.09</td>
<td>3</td>
<td>WWTP</td>
<td>(Kallenborn et al., 2004)</td>
</tr>
<tr>
<td>Europe</td>
<td>Germany</td>
<td>2009</td>
<td>1.64</td>
<td>&lt;0.39 - 1,356.00</td>
<td>20</td>
<td>Landfill</td>
<td>(Busch et al., 2010)</td>
</tr>
<tr>
<td>Europe</td>
<td>Norway</td>
<td>2004</td>
<td>1.9</td>
<td>3.7</td>
<td>3</td>
<td>WWTP</td>
<td>(Kallenborn et al., 2004)</td>
</tr>
<tr>
<td>Europe</td>
<td>Sweden</td>
<td>2012-2015</td>
<td>1.9</td>
<td>0.00 - 25.90</td>
<td>9 (100 %)</td>
<td>WWTP (9 wwt, 18 samples)</td>
<td>(Eriksson et al., 2017)</td>
</tr>
<tr>
<td>Europe</td>
<td>WWTP along River Elbe</td>
<td>2007</td>
<td>8.23</td>
<td>0.00 - 25.90</td>
<td>9 (100 %)</td>
<td>WWTP</td>
<td>(Ahrens et al., 2009b)</td>
</tr>
<tr>
<td>North America</td>
<td>San Francisco</td>
<td>2009</td>
<td>6.00 ± 6.50</td>
<td></td>
<td>3</td>
<td>WWTP</td>
<td>(Houtz et al., 2016)</td>
</tr>
<tr>
<td>North America</td>
<td>San Francisco</td>
<td>2014</td>
<td>2.70 ± 1.50</td>
<td></td>
<td></td>
<td>WWTP</td>
<td>(Houtz et al., 2016)</td>
</tr>
<tr>
<td>North America</td>
<td>USA (three temperate zones)</td>
<td>2013-2014</td>
<td>231.00 ± 577.33</td>
<td>3.44 - 3,410.00 (41.05)</td>
<td>87 (100 %)</td>
<td>Landfill (Ref organizes data based on climate zone and age)</td>
<td>(Lang et al. 2017)</td>
</tr>
</tbody>
</table>
Figure 16: Environmental concentrations of PFBS in waste water and leachate samples (ng/L).
4.5 Summary and Discussion of environmental distribution

The chemical properties of PFBS indicated that it is anticipated to be mainly present in aquatic media in the environment. In particular the high water solubility (miscible), extremely low Kaw/Daw (indicating negligible partitioning to air), and the log Koc value of 2.2 (implying that in soil containing 1% organic carbon the concentration per L water is similar to per kg soil), all collectively indicate PFBS will predominantly be transported by water. In the case of continuous or increasing emissions, PFBS will likely accumulate in water bodies, globally.

These expectations based on physical-chemical properties are largely supported by the literature review of monitoring data. PFBS was ubiquitously reported in oceanic/marine water samples, surface fresh water samples, and drinking water samples. It was noticeably less present in soil, sediment and air samples; however, there are noticeably fewer data these media compared to aquatic and biological media.

The affinity of PFBS for the water phase is also evident by the general trace concentrations being observed in many (though not all) aquatic biota samples. Trace concentrations were observed for the majority of marine, freshwater and terrestrial biota. For vegetation and plants there were relatively elevated concentrations. This is likely accounted for by PFBS mobility in water-soil systems, along with uptake through plant xylem.

4.6 Comparison with other PFAS

It is relevant to put this monitoring data in context with other regulated PFAS. In all of the studies included in this review of monitoring data, data for these and other PFAS have also been reported. However, comparing the concentrations on a study-by-study basis is complicated by the temporal changes in emission levels. Therefore, the data in these monitoring studies are first considered on the basis of temporal trends.

4.6.1 Temporal trends

PFBS was largely introduced into the market as a replacement chemical for PFOS (Olsen et al., 2009). It is anticipated, therefore, that as PFOS use has declined, that PFBS emissions have increased. Corresponding to this, as is presented in this section, several studies have reported that PFBS concentrations are increasing with time, and, unlike previously, several other recent studies have reported PFBS to be the dominating PFAS present in their monitoring study.

*Human blood.* Glynn et al. (2012) reported that over a time series from 1996-2010, PFOS in blood could be seen to be decreasing over time, but replacement substances like PFBS and PFHxS increased by 11% and 8.3% per year, respectively.

*Biota.* The first known measurement of PFBS in biota dates back to 2005, in a study on harbor Seals (van de Vijver et al., 2005). PFBS was rarely reported in Arctic marine
biota in samples prior to 2012, but is more common in more recent samples, particularly in polar bears (Section 4.4.2.1). Further indication that PFBS may be rising while PFOS levels are sinking is a time series observed in dolphin livers in the South China Sea, which reported the ratio of PFBS/PFOS concentrations in the liver has increased from 2002 to 2014 (Lam et al., 2016).

**Water.** The emergence of PFBS in the environment is particularly noticeable in water monitoring studies. In a global survey of surface water from 2016, both PFBS and PFOS were detected in all samples, however, PFBS was significantly higher in concentration, with the median PFBS/PFOS ratio being 3.9 (Pan et al. 2018). A recent survey of surface water in Northern Europe, with sampling in 2013, found PFBS to be the dominating PFAS, contributing 21% of the sum PFAS (Nguyen et al. 2012). Similarly, a survey of European and Chinese rivers from 2013-2014 found PFBS to be the dominating PFAS (average 15.6 ng/L), with PFOA (4.8 ng/L) and PFPeA (4.7 ng/L) in second and third place (Heydebreck et al., 2015). In the South China Sea, PFBS was one of the major PFAS analysed, contributing 21% of the total concentrations, along PFOA (~26%) and PFOS (~20%). In the Bohai Sea, PFBS was the third most abundant PFAS, after PFOA and PFHexA (Chen et al. 2016). A study in Chinese rivers in 2012 found PFBS to be the third largest contributor (Pan et al. 2014).

**Drinking water.** A study on drinking water from Brazil, France and Spain (Schwanz et al. 2016) reported that PFBS was one of the most frequently detected PFAS at 27.2% of samples, along with PFOS (100%), PFHpA (51.3%) and PFOA (23.0%). A global survey found similar results, with PFBS being the third most frequently detected PFAS in bottled water (47%) and tap water (88%) (Kabore et al. 2018).

**Source zones.** Increasing emissions of PFBS are noticed at source areas as well. Near a PFAS production facility in the Netherlands, PFBS was the dominating PFAS in both river samples (12-27 ng/L) and drinking water (0.5-19 ng/L) (Gebbink et al. 2017). Near the PFAS production facility at Tangxun Lake, China, the two most dominating PFAS in water were PFBA and PFBS, at means of 4770 and 3660 ng/L, respectively.

**WWTP and Landfills.** In a recent survey of WWTP in Sweden, PFBS, PFOS, and PFHxS had similar concentrations (1.9 ng/L, 1.9 ng/L, and 1.5 ng/L, respectively) (Erikkson et al. 2016). In San Francisco in 2014, PFBS was not the most dominating, but was emitted on average 2.7 ng/L, whereas PFOS and PFHxS were at 13 and 4.8 ng/L respectively.

Hence the most recent data collectively gives an indication that PFBS is one of the PFAS that is becoming the most commonly emitted, and is increasing in various environmental media, though in water in particular. If PFBS emission continue to increase, it follows that concentration in water samples and other environmental media would increase.
4.6.2 Maximum Concentrations

As an approximate indicator of the extent of PFBS contamination in different environmental media compared to other PFAS substances, maximum PFBS concentrations reported in this compilation are compared with those in previous compilations that were used to form the basis of regulations. These compilations include:


2) **PFOA (2013)**: BAuA (2013). Annex XV Dossier. Proposal for identification of a substance as a CMR1a or 1b, PBT, vPvB or a substance of an equivalent level of concern. Substance Name(s): Pentadecafluorooctanoic Acid (PFOA). EC Number(s): 206-397-9. CAS Number(s): 335-67-1

3) **PFDA (2016)**: Swedish Chemicals Agency and German Environment Agency (2016). Annex XV Dossier. Proposal for identification of a substance as a CMR1a or 1b, PBT, vPvB or a substance of an equivalent level of concern. Substance Name(s): Nonadecafluorodecanoic acid (PFDA) and its sodium and ammonium salts.


One caveat with this comparison is that neither the PFBS compilation in this report considers all published literature reports, and many of the compilations cited in the above references may be similarly incomplete (or outdated). This comparison of maximum concentrations is therefore just considered a qualitative comparison, and is not a quantitative presentation of actual maximum concentrations. This comparison for aquatic media is presented in Table 19 and for arctic biota in Table 20.

<table>
<thead>
<tr>
<th>Sample type</th>
<th>PFBS</th>
<th>PFHxS</th>
<th>PFOS</th>
<th>PFOA</th>
<th>PFDA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marine water</td>
<td>1.48</td>
<td>5.6</td>
<td>0.056</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Arctic water</td>
<td>2.15</td>
<td>24</td>
<td>-</td>
<td>0.21</td>
<td>19</td>
</tr>
<tr>
<td>Fresh water</td>
<td>1457</td>
<td>978.5</td>
<td>138</td>
<td></td>
<td>0.85</td>
</tr>
<tr>
<td>Drinking water</td>
<td>97.8</td>
<td>1770 (second max: 36)</td>
<td>63</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>WWTP effluent</td>
<td>26</td>
<td>5689</td>
<td>5290</td>
<td>1050</td>
<td>35</td>
</tr>
<tr>
<td>Landfill leachate</td>
<td>3410</td>
<td>16000</td>
<td>-</td>
<td>-</td>
<td>55.1</td>
</tr>
</tbody>
</table>

**Refs**

As evident from Table 19, the maximum concentration for PFBS in freshwater (1457 ng/L) is highest amongst the considered PFAS compilations, followed by PFHxS at 978.5 ng/L. PFBS had the second highest maximum concentration for drinking water (97.8 ng/L), due to the maximum for PFHxS being 1770 ng/L. However, this is an outlier as the second highest value for PFHxS was 35 ng/L. There were several drinking water samples of PFBS containing more than 35 ng/L in this compilation, so another metric could have said PFBS is the more contaminating in drinking water than PFHxS. The maximum artif fresh water concentration for PFAS at 2.15 ng/L is larger than PFOA (0.21 ng/L), but not as large as maximum values for PFHxS (24 ng/L) and PFDA (19 ng/L). The maximum concentration in non-Arctic marine water for PFBS at 1.48 ng/L have been report is larger than PFOS (0.056 ng/L) but not PFHxS (5.6 ng/L). PFBS can therefore be considered to be reaching or to have reached concentrations in aquatic media that are similar or higher than those previously observed for regulated PFAS substances, during the time they were becoming regulated.

Table 20. Comparison of maximum concentrations of PFBS, PFHxS, PFOS, PFOA and PFDA in various compilations for arctic biota (ng/g ww).

<table>
<thead>
<tr>
<th>Sample type</th>
<th>PFBS</th>
<th>PFHxS</th>
<th>PFOS</th>
<th>PFOA</th>
<th>PFDA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polar Bear Liver</td>
<td>0.04</td>
<td>&gt; 500</td>
<td>4000</td>
<td>36</td>
<td>103</td>
</tr>
<tr>
<td>Glaucus Gull Eggs</td>
<td>&lt;0.08</td>
<td>1.23</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mink Liver</td>
<td>0.33</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ringed seal liver</td>
<td>&lt;0.002</td>
<td>nd - 3</td>
<td>1.01</td>
<td></td>
<td>2.5</td>
</tr>
</tbody>
</table>


As evident from Table 20, though PFBS is appearing in arctic biota, it is currently at much smaller concentrations than observed for other PFAS (for which the data for the same media is available). For instance, for polar bear liver, the current maximum concentration for PFBS is 0.04 ng/L, which is less than the maximum observed for PFOS (4000 ng/L), PFHxS (>500 ng/L), PFOA (36 ng/L) and PFDA (ng/L).

It is concluded from this quick, qualitative comparison that in the short term PFBS has the potential to contaminate water resources more so than PFHxS, PFOS, PFOA and PFDA has. Over the short term in arctic biota, it is unlikely PFBS will reach the same levels as PFHxS, PFOS and PFOA attained in previous studies.

5 Data indicating potential for long-range transport

PFOS and PFHxS have been shown to contaminate the Arctic through long-range transport. It can be expected simply based on read-across from the physicochemical properties that PFBS should also contaminate the Arctic. For extremely persistent substances, the two key critical parameters to predict long range transport is the Kaw and the Koa (Meyer and Wania, 2007); though, as discussed in section 2 for ionic substances like PFAS, one should use the Daw rather than Kaw, and Koc,a rather than
Koa (Armitage et al. 2009). Recalling from Table 2, the log Koc,a values for PFBS (4.8) is very similar to PFHxS (5.0) and PFOS (4.7). The log Daw values at pH 8 for PFBS (-14.5) are considered extremely low, similar to PFHxS (-13.8) and PFOS (-13.1), such that volatilization from water to air for all substances is negligible. Therefore this combination of physical-chemical properties implies that PFBS will reach and accumulate in the Arctic under steady state emissions, similar to PFOS and PFHxS.

Supporting this expectation is the large number of measurements that have found PFBS in the Arctic and Antarctic regions, where it is commonly found in Artic biota and Antarctic water samples (Section 4.4.5.1 and 4.6.2). The major difference with PFBS regarding the arctic presence of PFBS compared to PFHxS and PFOS is that PFBS is less present in Arctic (Section 4.4.2.1 and 4.2.6), where it is only found in a few samples with considerable levels. This is related to the lower anticipated bioaccumulation potential of PFBS compared to longer chain PFAS, as described in pharmokinetic studies (Olsen et al. 2009) and in Section 6.

The ubiquitous presence water samples in general (Sections 4.4.4 to 4.4.5) is an additional indicator of PFBS being able to undergo long range transport via the water phase. It was found in all marine (oceanic) samples, both near shore and far at sea (Section 4.4.4). It is also found in remote freshwater environments and even groundwater (4.4.5.3 and 4.4.5.4). PFBS' ubiquitous presence in drinking water and bottled water, at locations near and far from PFBS sources, is another indicator for long range transport. To reach drinking water, PFBS has to first be transported from the point of emission to the source of the drinking water (raw water), and then it would have to survive drinking water production. Though not all of the drinking water treatment preparation steps were considered individually in section Section 4.4.5.5, collectively they would include some kind of filtration (e.g. bank filtration, sand filtration), and in many cases involve more advanced filtration (e.g. activated carbon) or oxidation processes (like ozonation). Studies of PFAS during drinking water production have indicated conventional methods are not effective at PFAS removal (Rahman et al. 2014); thereby, PFAS removal from drinking water requires dedicated (and costly) setups.

6 Bioaccumulation - Field Data

The presence of PFBS in biota was presented in Section 4.4.2, and in humans in 4.4.5. It appears that PFBS can be quantified in several biological matrices. The concentrations in these matrices, however, are in general less than observed for longer chain PFAS substances, like PFHxS and PFOS, as discussed in section 4.6.2.

There have been several studies that indicate that PFBS is rapidly excreted after introduction, for instance in rats (Olsen et al., 2009b) and cows (Kowalczyk et al., 2013); in humans half-lives in blood/plasma up to 46 days have been measured (Olsen et al, 2009). However, if animals and humans are continuously exposed to increasing environmental concentrations of PFBS, the excretion pathway is less relevant, as biota would reach some equilibrium with the exposure concentrations.
The enrichment of PFBS in plants is more substantial than accumulation in animals. This is indicated by the relatively high concentrations of PFBS reported in plants grown on PFAS contaminated soil, compared to other biota. This is relevant for exposure considerations, as it indicates that humans and animals can be exposed to PFBS both through drinking water and vegetation in PFAS contaminated areas, particularly farmland.
7 References


Axelson, S. Perfluoroalkyl substances in Arctic birds - A comparison between glaucous gulls and black guillemots from Svalbard, MSc thesis, SLU Sweden, 2014


Kwok, K. Y., Taniyasu, S., Yeung, L. W., Murphy, M. B., Lam, P. K., Horii, Y., ... & Yamashita, N. (2010). Flux of perfluorinated chemicals through wet deposition in Japan, the United States, and several other countries. Environmental science & technology, 44(18), 7043-7049.


Miljødirektoratet (2016). Environmental pollutants in the terrestrial and urban environment 2015, M-570


Prepared by the intersessional working group on PFHxS, its salts and PFHxS-related compounds. Persistent Organic Pollutants Review Committee. September 2018.


REACH registration dossier PFBS-K-salt, September 2018 (EC: 249-616-3)

REACH registration dossier PFBS, September 2018 (EC: 206-793-1)


Skaar J. S., Occurrence of Selected Poly- and Perfluoroalkyl Substances (PFAS) in Arctic Freshwater: A Case Study from Svalbard, MSc thesis, NMBU Norway, 2016


Appendix

Table A1. Latin names of biota presented in this report

<table>
<thead>
<tr>
<th>Common Name</th>
<th>Latin Name</th>
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<tbody>
<tr>
<td>Black crappie</td>
<td>Pomoxis nigromaculatus</td>
</tr>
<tr>
<td>Black guillemot</td>
<td>Cepphus grylle</td>
</tr>
<tr>
<td>Bluegill</td>
<td>Lepomis Macrochirus</td>
</tr>
<tr>
<td>Carp</td>
<td>Cyprinus carpio</td>
</tr>
<tr>
<td>Catfish</td>
<td>Siluriformes</td>
</tr>
<tr>
<td>Celery</td>
<td>Aptium graveolens var. Dulce</td>
</tr>
<tr>
<td>Chinese bitterling</td>
<td>Rhodeus sinensis Gunther</td>
</tr>
<tr>
<td>Cod</td>
<td>Gadus morhua</td>
</tr>
<tr>
<td>Common eider</td>
<td>Somateria mollissima</td>
</tr>
<tr>
<td>Common gull</td>
<td>Larus vanus</td>
</tr>
<tr>
<td>Cow</td>
<td>Bos taurus</td>
</tr>
<tr>
<td>Crucian</td>
<td>Carassius cuvieri</td>
</tr>
<tr>
<td>Earthworms</td>
<td>Lumbricidae</td>
</tr>
<tr>
<td>European shag</td>
<td>Phalacrocorax aristotelis</td>
</tr>
<tr>
<td>Freshwater mussel</td>
<td>Lamellibranchia</td>
</tr>
<tr>
<td>Glaucus gull</td>
<td>Rissa tridactyla</td>
</tr>
<tr>
<td>Gobies</td>
<td>Ctenogobius giurinus</td>
</tr>
<tr>
<td>Green turtle</td>
<td>Chelonia mydas</td>
</tr>
<tr>
<td>Guillemot</td>
<td>Uria aalge</td>
</tr>
<tr>
<td>Harbor porpoise</td>
<td>Phocoena phocoena</td>
</tr>
<tr>
<td>Hawksbill turtle</td>
<td>Eretmochelys imbreicata</td>
</tr>
<tr>
<td>Herring</td>
<td>Clupea harengus membras</td>
</tr>
<tr>
<td>Herring Gull</td>
<td>Larus argentatus</td>
</tr>
<tr>
<td>Kemp's ridley turtle</td>
<td>Lepidochelys kempii</td>
</tr>
<tr>
<td>Killer whale</td>
<td>Orcinus orca</td>
</tr>
<tr>
<td>Kittiwake</td>
<td>Larus hyperboreus</td>
</tr>
<tr>
<td>Lake saury</td>
<td>Coilia mystus</td>
</tr>
<tr>
<td>Lake shrimp</td>
<td>Macrobranchium nipponense</td>
</tr>
<tr>
<td>Leatherback turtle</td>
<td>Dermochelys coriacea</td>
</tr>
<tr>
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</tr>
<tr>
<td>Mink</td>
<td>Neovison vison</td>
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<tr>
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<td>Mongolian culter</td>
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<td>Pearl mussel</td>
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<td>Pilot whale</td>
<td>Globicephala melas</td>
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<tr>
<td>Polar bear</td>
<td>Ursus maritimus</td>
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<td>Common Name</td>
<td>Latin Name</td>
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<tr>
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<tr>
<td>Pumpkinseed</td>
<td><em>Lepomis gibbosus</em></td>
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<td>Radish</td>
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<td>Ringed Seal</td>
<td><em>Pusa hispida</em></td>
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<td>Shark</td>
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<td>Silver carp</td>
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<tr>
<td>Sprat</td>
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<td>Tilapia</td>
<td><em>Tilapia</em></td>
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<tr>
<td>Tomato</td>
<td><em>Lycopersicon lycopersicum</em></td>
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<tr>
<td>White shrimp soft tissue</td>
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<td>Whitebait muscle</td>
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Emneord/Keywords
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<td>Hans Peter Arp</td>
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