Surface Water Quality Considerations for Per- and Polyfluoroalkyl Substances (PFAS)

ITRC has developed a series of fact sheets that summarizes recent science and emerging technologies regarding PFAS. The information in this and other PFAS fact sheets is more fully described in the ***ITRC PFAS Technical and Regulatory Guidance Document (Guidance Document)*** (https://pfas-1.itrcweb.org/).

This fact sheet describes considerations for managing PFAS impacts to surface water, including:

- Beneficial uses of surface water impacted by PFAS
- Regulatory approaches for developing surface water quality criteria and guidance values
- Sampling and analysis considerations for surface water quality assessments, including surface water foam

1 Introduction

This fact sheet summarizes the emerging technical information available to support the development of regulatory criteria or guidance values to protect the beneficial uses of surface water (including as a drinking water source). This fact sheet also highlights considerations for sampling and analysis for surface water qualtiy assessments for PFAS. The information in this fact sheet is based on Section 16 of the Guidance Document.

2 Regulatory Criteria and Beneficial Uses

Regulatory agencies may choose to develop and implement numeric surface water quality criteria (or guidance values) to protect the beneficial uses of surface water that may be negatively impacted by PFAS. The regulatory criteria selected for a water body are generally the most stringent of all of the values identified for each beneficial use for a water body. Surface water criteria do not consider analytical or treatment removal factors.

The Guidance Document focuses on the following beneficial use groupings that might be impacted by the presence of PFAS (see Section 16.1.1):

- drinking water source
- habitat for aquatic life and wildlife
- human consumption of aquatic organisms
- human contact with water during recreation, considering exposure due to incidental ingestion and dermal contact with surface water, sediments, and potentially PFAS-containing foam
- agricultural supply, considering farming, horticulture, dairy operations, ranching, watering of livestock, and use for irrigation of crops for consumption by humans or livestock (i.e., crop uptake), with potential human exposures through skin contact and inhalation of PFAS in irrigation water, as well as consumption of PFAS in livestock or crops contaminated by irrigation water
- natural and artificial groundwater recharge, with considerations similar to those for drinking water and agricultural supply beneficial uses

In general, for PFAS, the two most relevant beneficial uses are drinking water use and consumption of aquatic organisms that may take up and bioaccumulate PFAS from the surface water into their tissue.

To date, the U.S. Environmental Protection Agency (USEPA) has published draft surface water and biota tissue criteria protective of aquatic life for perfluorooctanoic acid (PFOA)(USEPA 2022 Ref#2300) and perfluorooctane sulfonic acid (PFOS)(USEPA 2022 Ref#2302). Currently, only a few states have formally established surface water criteria for PFAS that are protective of surface water uses. Available standards or criteria, where established by states, are presented in the Water and Soil Values Table posted on the fact sheets page (https://pfas-1.itrcweb.org/fact-sheets).

Once a protective value for a water body has been established, regulatory mechanisms can be used to protect the water body to maintain or reduce the concentrations to below the protective values. Examples of these regulatory mechanisms include National Pollutant Discharge Elimination System (NPDES) discharge permit effluent limits for point sources, non-NPDES permits and best management practices for nonpoint sources, and assigned loadings from all sources to a water body through total maximum daily loads (TMDLs).

3 Derivation of Numerical Criteria

Currently, development of criteria for PFAS focuses on the two main beneficial uses of: (i) the protection of human health from exposure to PFAS in surface water, such as ingestion of drinking water and consumption of fish and other aquatic species; and (ii) the protection of biota, based on available ecotoxicity data, bioaccumulation and concentration factors, and aquatic-dependent wildlife considerations, among others.

Protection of Human Health

At this time, exposure pathways involving ingestion are the most significant routes of PFAS exposure to humans. Protection of human health can be achieved using enforceable, risk-based numeric surface water quality criteria or nonmandatory, risk-based guidelines and advisories that are developed for specific water bodies for the protection of drinking water sources and fish consumption uses based on acceptable fish tissue concentrations (USEPA 2000 Ref#1686).

Human health criteria are developed using toxicity values and exposure assumptions. The toxicity values used for both human health criteria and fish consumption advisories are reference doses (RfD; ng/kg/day or mg/kg/day) for noncarcinogenic effects and cancer slope factors (CSF; $[\text{mg/kg/day}]^{-1}$) for carcinogenic effects. A risk level (for example, 1 in 1,000,000; 1 in 100,000) must also be selected for criteria for carcinogenic effects. The toxicity values used for PFAS vary among agencies based on different selections of critical toxicological effect, uncertainty factors, and other considerations. States may base their water quality criteria and fish consumption advisories on toxicity values recommended by USEPA or sources other than USEPA, or may develop their own toxicity values. Currently, the USEPA has not established human health surface water criteria for any PFAS, and toxicity values for a limited number of PFAS are at different stages of development and adoption for use in human health risk assessment..

Exposure assumptions also may vary among agencies according to the target population relevant to the chemical's health effects and agency preference. For surface water criteria, the target population is usually adults, but sensitive subpopulations such as nursing mothers and children may also be considered. In the development of human health water quality criteria for waters designated for drinking water use, based on standard exposure assumptions, the relative dose from fish consumption versus drinking water is dependent on the bioconcentration factor (BCF) or bioaccumulation factor (BAF), as well as the assumed rate of ingestion of drinking water and aquatic organisms. Exposure from ingestion of aquatic organisms will be greater than exposure from drinking water for those PFAS with substantial bioaccumulation potential in aquatic organisms. (Table 5-1, see the External Data Tables on https://pfas-1.itrcweb.org).

Using USEPA methodology, the human health criteria can be derived using a variant of the equation in the text box (USEPA 2000 Ref#1686). Equation terms accounting for exposure from drinking water (drinking water ingestion rate) or fish consumption (BAF or BCF; fish ingestion rate) can be removed as appropriate for the designated use of the water body.

Standard USEPA Equation for Noncarcinogen Criterion for Combined Drinking Water Ingestion + Fish/Shellfish Consumption

$$SWC = \frac{RfD \times BW \times RSC}{DWIR + ((BCF \text{ or } BAF) \times FIR)}$$

SWC = surface water criterion (mg/L)
RfD = reference dose (mg/kg/day)
BW = body weight (kg)
RSC = relative source contribution (unitless)
DWIR = drinking water ingestion rate (L/day)
BCF = bioconcentration factor (L/kg)
BAF = bioaccumulation factor (L/kg)
FIR = fish intake rate (kg/day)

Protection of Biota

In addition to human health-based water quality criteria, regulatory agencies develop criteria to protect ecological receptors. There are generally two categories of these criteria: aquatic life and aquatic-dependent wildlife. Aquatic life, such as fish and invertebrates, live in water bodies and have both direct and indirect exposure to contaminants. Aquatic-dependent wildlife, such as birds and mammals, consume fish and other biota that live in water bodies and have indirect exposure via the food chain. Different criteria are specified for freshwater and saltwater aquatic life, and for short-term (acute) and longer term (chronic) exposures and effects.

USEPA has a standard approach for deriving aquatic life criteria that is based on a compilation of acute and chronic toxicity data, when available, for eight taxonomic groups (USEPA 1985 Ref#1610) (Section 16.3.2 of the Guidance Document). To date, most aquatic toxicity data are for PFOS and PFOA, and therefore, PFOS and PFOA are the only PFAS for which USEPA has currently developed draft criteria (USEPA 2022 Ref#2302; USEPA 2022 Ref#2300). There are limited data for PFNA, PFBA, and PFBS (see Section 7.2 of the Guidance Document).

Aquatic life-based surface water quality criteria may not be protective of wildlife, particularly for bioaccumulative PFAS such as PFOS. It therefore may be necessary to calculate a criterion that addresses wildlife exposure via food chain transfer. This criterion would be calculated in a manner like that used to derive a criterion for human health—the criterion is calculated using assumptions about wildlife food and water intake (specific to the relevant receptor, such as herons or mink that eat fish or other aquatic organisms), toxicity values derived for wildlife, and a BAF or BCF (USEPA 1995 Ref#1802). As noted in Section 16.3.3 of the Guidance Document, development of such criteria is in its infancy because (i) there are few laboratory or field studies with data on the toxicity of PFAS to wildlife, (ii) there are limited data on PFAS in the diet of aquatic-dependent wildlife, and (iii) the unique properties of PFAS make modeling of food chain uptake complicated.

4 Sampling and Analysis Considerations

Collecting samples for the analysis of PFAS in surface water, sediment, biota, and PFAS-containing foam should be tailored to meet sampling objectives to support site characterization and water quality assessments. As described in Section 11.1 of the Guidance Document, special considerations for PFAS sampling include the types of sample equipment or materials used due to the widespread uses for and products containing PFAS and the need for low laboratory quantitation limits. Refer to the Guidance Document Section 11.2, and the Analytical Methods Excel File (Tables 11-2, 11-3, 11-4, and 11-5, see the External Data Tables on https://pfas-1.itrcweb.org). The media to be sampled should be determined based upon the assigned beneficial use of the water resource under evaluation and the potential receptors of concern.

Surface Water

Due to the chemical properties of PFAS, concentrations in the surface water near the discharge location may be higher at or near the surface. As noted below, if present at a site, PFAS-containing foam may contain PFAS levels several orders of magnitude higher than the underlying water column. Depending on study objectives, these zones of higher potential contamination should be avoided or targeted during sample collection.

Sediment

Sediment can be a contaminant sink, a transport mechanism, or a source of contaminants to a surface water body (and to benthic organisms). It may therefore be necessary to sample sediment for PFAS to support an understanding of its contribution to the surface water quality or biota tissue concentrations. When using conventional sediment sampling and coring techniques, ensure that material in contact with the samples is PFAS free (for example, no PFAS-based coatings).

Biota

Because some PFAS are known to accumulate in aquatic biota and in some instances may drive the development of surface water quality criteria, sampling for biota may be an important component of a monitoring plan. Careful consideration should be given to species selection, size range, and tissue type(s) (for example, fish fillet or whole-body fish) selected for analysis. Additional considerations include sampling surface water and sediment within the same area from which the biota are collected and where the biota are exposed to PFAS. While it is recognized that many aquatic biota are migratory or exhibit extended home ranges, this information will help support identification of PFAS sources as well as potentially the development of site-specific BCFs, BAFs, and biota-sediment accumulation factors (BSAFs) (Table 5-1, see the External Data Tables on https://pfas-1.itrcweb.org).

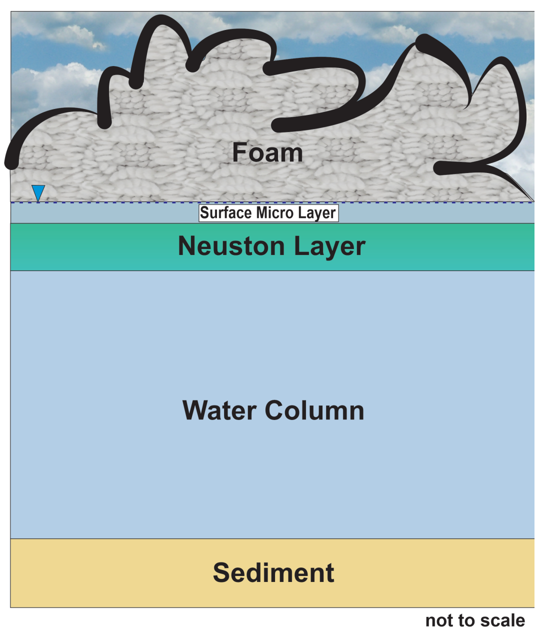

Figure 1. PFAS-containing foam on surface water.

Source: PFAS-1, Figure 16-2.

Surface Water Foam

PFAS-containing foam can form on surface waters when dissolved-phase PFAS are agitated by wind or wave action, and aggregate into a mass at or above the surface of the water. PFAS-containing foam may have a wide variety of visual and textural appearances (MPCA 2020 Ref#1819). Figure 1 includes a representation of PFAS-containing foam on surface water.

Foam can present a significant source of uncertainty in surface water assessments. As foam is formed, it removes PFAS from the water column; concentrated PFAS-containing foam can therefore be found on surface water bodies containing nondetectable to low PFAS concentrations. Although it is typical to find PFAS-containing foam near sources of release, such foams can also occur some distance away. Foam can break apart and be transported downstream as “foam islands,” which can then partition back into solution in the water column, increasing surface water PFAS concentrations at locations far from the initial source. Risks associated with exposure to PFAS-containing foam are not well understood at this time. It should be understood that the presence of foam does not necessarily mean that PFAS are present as foam can naturally form with the presence of dissolved organic matter in water with a lowered surface tension and turbulent conditions.

Sampling protocols should specify where in the foam or water column the sample is to be collected. The Michigan Department of Environment, Great Lakes, and Energy (EGLE) has published a surface water foam sampling guidance and a surface water foam study report, (MI EGLE 2019 Ref#1818; MI EGLE 2021 Ref# 1932). PFAS-containing foam may occur at and above the air-surface water interface, as shown in Figure 1. The foam itself is the visible upper layer and is likely to be characterized by PFAS concentrations that are much higher than those found in the underlying surface water column. Similarly, the surface micro layer (SML), which is present at the air-water interface and is only about 50 μm thick, typically contains the highest PFAS concentrations of all the layers (MPCA 2020 Ref#1819). Determining which portions of the foam layers should be sampled is dependent on the data quality objectives, as inclusion of foam or the SML in the sample will likely result in higher concentrations than if just the water column and neuston layer are sampled. The neuston layer (the zone directly underlying the SML typically enriched with biological life) comprises the base of the aquatic food web (Wurl et al. 2017). PFAS concentrations in this layer may be important to consider for ecological risk assessments and trophic transfer studies.

The analytical laboratory should be warned that there may be very high levels of PFAS in PFAS-containing foam, so that it can take the necessary precautions to avoid instrument failure during analysis.

5 Effluent Limits for PFAS

The protection of surface water quality from the impacts of discharges from publicly own treatment works (POTWs) and industrial wastewater treatment works is based on the establishment of effluent limits for pollutants in the discharges from those facilities. The effluent limits are enforced through National Pollution Discharge Elimination System (NPDES) permits. Those effluent limits are developed by establishing technology-based (TBELs) and water quality-based (WQBELs) effluent limits for a specific pollutant and using the most restrictive value of the two for the final effluent limit in the permit. Currently, only North Carolina has an NPDES permit with TBELs for PFAS and Minnesota has adopted an NPDES permit with WQBELs for PFOS.

Effluent limits are also informed by effluent limit guidelines (ELGs) that are national wastewater discharge standards developed by EPA on an industry-by-industry basis. These are technology-based regulations that are intended to represent the greatest pollution reductions that are economically achievable for an industry. The standards for direct dischargers are incorporated into NPDES permits issued by States and EPA regional offices and permits or other control mechanisms for indirect dischargers (https://www.epa.gov/eg/learn-about-effluent-guidelines).

As of the date of this document, there are no USEPA established ELGs for PFAS. USEPA outlined an approach for establishing ELGs for select PFAS in its PFAS Strategic Roadmap (USEPA 2021[2223]) and released its Effluent Guidelines Program Plan 15 in 2023 (USEPA 2023 Ref#2745 (See Section 16.6.5).

6 References and Acronyms

The references cited in this fact sheet and further references can be found at https://pfas-1.itrcweb.org/references/. Reference numbers are included in this fact sheet for non-unique citations in the Guidance Document reference list.

The acronyms used in this fact sheet and in the Guidance Document can be found at https://pfas-1.itrcweb.org/acronyms/.

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