Guidance for Assessment of Per- and Polyfluoroalkyl Substances (PFAS) in Fish and Other Aquatic Organisms

The Agency for Toxic Substances and Disease Registry

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Introduction and Intended Use of this Guidance

Objective

This guide describes the process of conducting a health assessment in areas with potential per- and polyfluoroalkyl substances (PFAS) exposure via consumption of fish or other aquatic organisms that are locally harvested and consumed. Reviews of literature and existing methods recommended for the assessment of PFAS in fish are provided. This guidance is intended to help the Agency for Toxic Substances and Disease Registry (ATSDR) staff, state health departments, and others when measuring and evaluating exposures to PFAS in fish.

Background

ATSDR and its partners conduct quantitative assessments to determine whether, and to what extent, people have been, are being, or may be exposed to hazardous chemicals; and if so, whether the exposures are potentially harmful to health and should be prevented or reduced. These quantitative assessments are used to characterize exposures to specific contaminants and are always preceded by an initial qualitative assessment to evaluate the potential for exposure to hazardous chemicals. ATSDR, the United States Environmental Protection Agency (EPA), state partners, or other stakeholders may perform the initial assessment. Exposure Investigations (EIs) incorporate environmental and/or biological sampling, and modeling to answer specific questions surrounding exposure. The anticipated use of the data and its expected impact on public health should be clearly described prior to any sampling.

Additional Considerations/ Limitations to this Guidance

This guidance is not comprehensive. Users should consult the references provided for more details. Because PFAS are emerging contaminants and information related to their toxicity and environmental fate may change as a result of new research, health assessors should apply the best current science when evaluating exposures to PFAS. The methods, literature citations, and regulatory values discussed in this document are current as of its drafting in August 2018.

The exact way in which PFAS gets into fish is unknown. While there are methods to measure a number of PFAS, at the time this guidance was drafted, all current fish consumption guidance and regulations on PFAS in the U.S. are based on the concentration of perfluorooctane sulfonate (PFOS) in fish tissue and surface waters. PFOS has been found in many species of wildlife around the world, including fish, and can accumulate in edible tissues to levels that could be of human health concern.

The half-life of PFOS in fish is shorter than in humans or the environment. Thus, concentrations in fish decline more rapidly following declines in surface water concentrations. Studies have shown that PFOS is measured more often and at higher concentrations in fish tissue than other PFAS compounds [Stahl, 2014]. While other forms of PFAS may also be toxic, in the U.S. they are not included in the calculation of risk of PFAS exposure from consumption of fish. At the time this guidance was drafted, ATSDR only found regulations in Australia and New Zealand

that were based on the concentration of additional PFAS chemicals in fish tissue (Perfluorooctanoic acid [PFOA] and Perfluorohexanoic acid [PFHxA]).

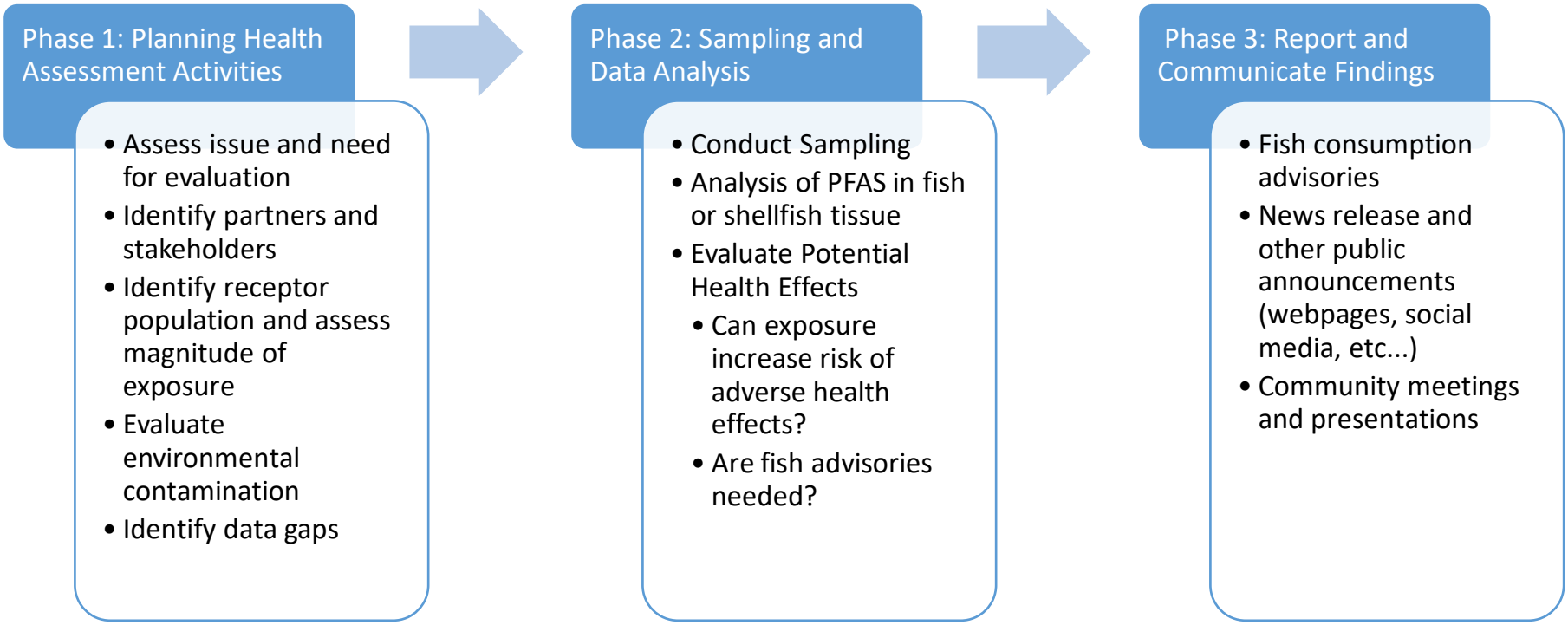
The analytical methods used to analyze PFAS generally include measures of several different PFAS at once. Although PFOS is the only PFAS used to issue fish consumption advisories in the U.S., if substantial amounts of other PFAS are measured they should also be discussed using the best science available.

There are many health benefits derived from eating fish that outweigh the risk from the presence of a contaminant. Communities with measured levels of contaminants in fish should be advised on how to catch, eat, and cook fish safely. Fishing has a profound cultural and economic significance in some communities, thus it is important to collaborate with the affected communities in the delivery and interpretation of the health assessment findings.

Road Map for Health Assessments with Potential PFAS Exposures from Fish Consumption

In general, there are three phases in the assessment process: Planning, Sampling and Data Analysis, and Communication of Results (see Figure 1).

Figure 1. Road Map for Health Assessments with Potential Exposures to Per- and Polyfluoroalkyl Substances (PFAS) from Fish Consumption



Phase 1 – Planning Health Assessment Activities

Assess Issue and Need for Evaluation:
Determine what triggered initial interest at the site and answer the following questions.

- Is there a known source or specific site at which a PFAS release to the environment occurred (in some cases there may not be a distinct or recognized release site)?
- Are there any data with elevated PFAS levels in local bodies of water where people fish?
- Is there a formal request for assistance? Are there community concerns or interest in exposures to PFAS?
- Is the site on federally-owned land or is it related to the Department of Defense?
- If there is not a specific request, what are the needs, goals, etc. for health assessment activities that can be identified initially?

Identify Partners and Stakeholders:
Consider who should be informed or included in the evaluation. Especially, is there an existing state fish consumption advisory program that covers the area? Where can pertinent data be obtained? Who can help identify community concerns?

It is important that the affected community is consulted when defining the key question(s) that need to be answered, and when planning and conducting health assessment activities. The affected community includes the receptor population at a minimum.

Identify Receptor Population and Magnitude of Exposure:
Consider if contamination of fish is possible and whether or not people are likely to consume them. If so, who is being exposed? Are there any vulnerable subpopulations or other high-risk groups that warrant special attention in the evaluation? Some populations may be especially vulnerable and at higher risk for exposure if a certain contaminated species is only eaten by a specific subgroup within the community. For example, culturally specific preparation of fish may increase exposure, and specific populations may consume locally caught fish at a higher rate than other groups.

If fish consumption represents a completed pathway, identify the exposed population and characterize the exposure. Find out what fish the population consumes, what parts are consumed, how it is prepared, how much is eaten, and how frequently. Determine if data are available that show concentrations of PFAS in locally caught fish or their associated waterbodies. (e.g. PFAS surface water levels).

Evaluate Environmental Contamination:
Obtain and review available environmental data to determine the extent of PFAS contamination, the location of the source, and possible human exposure pathways. Useful data may include historical data (maps, land use, operations, etc.), environmental investigation results, and fate and transport predicted for the location and chemicals of interest. Include data necessary to understand historical and future fate and transport of PFAS from any known source(s).

Identify Data Gaps:
If available data are not adequate to evaluate exposure to PFAS via consumption of fish, develop recommendations for targeted environmental and/or biological sampling to collect those data needed to determine the magnitude of exposure to the defined receptor population.

Prior to any fish sampling, it is vital to determine and clearly articulate the gaps in data that will be addressed by sampling and the resulting impact on public health. Some key questions and data necessary to evaluate the potential for PFAS exposure via fish consumption include the following.

Question: Are fish harvested (and actually consumed) from water bodies that are or may be contaminated?

Data Needed: Determine fish harvest patterns from knowledgeable sources (e.g. local fishermen and local agencies). Conduct water sampling for PFAS in the areas of interest. If water body is located near the source of contamination and no data is present, assume the water body is contaminated and proceed with investigation.

Question: How much and how often are harvested fish consumed?

Data Needed: Determine fish consumption patterns from knowledgeable sources or assume patterns using appropriate default assumptions. This may include information such as who eats the fish, the type of fish, how much is eaten, how frequently it is eaten, which parts are eaten, and how the fish are prepared.

Question: Are portions of the fish that are consumed contaminated?

Data Needed: Test appropriate/representative fish tissue samples for PFAS. The decision unit for fish data (e.g. tissue sampling results) could include water body (and possibly location within a body), time of year, fish species, and possibly size of fish. The decision unit should be representative of exposures that people do or may realistically receive, and should be aligned with practical advisories that audiences understand and follow. Considerations of representativeness may depend on goals and expectations of the health assessment effort and resources available.

Phase 2 – Sampling and Data Analysis

Conduct Sampling:
Targeted sampling and sample processing should be conducted using standard methods so that data collected are reliable. Sampling may include consumption surveys and/or analysis of PFAS in fish tissue to estimate exposure to PFAS. See *PFAS Fish Sampling Strategies* (page 8) for additional information.

Analysis of PFAS in Fish or Shellfish Tissue:
Although similar methods are used, there is currently no standard analytical method, from EPA or any voluntary consensus standard bodies, for PFAS analysis in fish tissue. Few laboratories advertise of fish tissue analysis for PFAS.

Evaluate Potential Health Effects:
The health effects evaluation attempts to answer whether the exposure could result in harmful effects. If possible, follow the existing local fish consumption advisory program process to determine public health implications of the assessed pathway. If an existing process is not available, consult with experts to identify methods for assessment that are acceptable to the community and key stakeholders. See *Fish Consumption Guidance Methodology* (page 17) for additional information.

Phase 3 – Report and Communicate Findings

Several products and methodologies may be used to communicate findings to the intended audiences. Some examples are listed below:

- Issuance of fish consumption guidelines or advisories
- Development of outreach and educational material related to safe consumption of fish and/or shellfish from affected waters bodies.
- News releases and other public service announcements (radio, newspapers, social media, etc.).
- Community meetings and town hall presentations.

A community education and outreach event are often helpful. Interpretation of health assessment results or findings, including key messages and messaging method, should be developed with input from local stakeholder and the affected communities.

PFAS Fish Sampling Strategies

The following is a general guide describing fish sampling methodology for PFAS. The EPA and several states have standard operating procedures for fish collection and processing. The collection and processing steps for PFAS in fish are not different from those of other well-studied contaminants, such as mercury and polychlorinated biphenyls (PCBs). In general, the steps include the following:

F. Determine fish consumption rates of locally harvested fish [EPA, 2016]
G. Determine sampling sites [EPA, 2000a]
H. Determine the fish species and size to sample [EPA, 2000a]
I. Catch, label, and process fish for shipping to the lab [EPA, 2000a]
J. Laboratory resection, processing, and analysis [Delinsky *et al.*, 2009; Stahl *et al.*, 2014]

A. Determine fish consumption rates of locally harvested fish

Consumption patterns, including the type(s) and quantity of fish consumed, parts of fish consumed, consumption patterns, and the cooking methods utilized, can vary greatly within populations due to the differences in age, sex, cultural practices and/or socioeconomic status.

If possible, health assessors should use state-derived fish consumption rates, or others derived from relevant local data. Surveys can also be used within the community to determine fish consumption, but the design of surveys is intimately linked to the survey objectives, and care must be taken in using the results of surveys designed for other purposes. For more detailed guidance on fish consumption surveys, see EPA's 2016 *Guidance for Conducting Fish Consumption Surveys* [EPA, 2016].

If local fish consumption data are not available, screening calculations can be performed using the most relevant values from the EPA Exposure Factors Handbook [EPA, 2011]. This handbook offers fish consumption rates for the general population (separated into age groups), recreational consumers of marine fish, recreational consumers of freshwater fish, and specific Native American groups. The latest edition of the Exposure Factors Handbook was released in 2011, but since October 2017, EPA has begun to release chapter updates individually to allow risk assessors to get the latest information as new data becomes available. (See https://www.epa.gov/expobox/about-exposure-factors-handbook)

B. Determine sampling sites

Sampling sites should be selected to identify extremes of the bioaccumulation spectrum, ranging from presumed undisturbed reference sites to sites where existing data (or the presence of potential pollutant sources) suggest significant chemical contamination. Where resources are limited, investigators initially should target those harvest sites suspected of having the highest levels of contamination and of posing the greatest potential health risk to local fish consumers. Study sites should be located in frequently fished areas with a potential for contamination. See EPA's *Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories. Volume 1: Fish Sampling and Analysis* for more details on selection of sampling sites [EPA, 2000a].

C. Determine the fish species and size to sample

According to the 1993 EPA Fish Contaminant Workgroup, the most important criteria for selecting target fish species for state contaminant monitoring programs assessing human consumption concerns is that the species are either commonly consumed in the study area or are of commercial, recreational, or subsistence fishing value. EPA recommends that states use the same criteria to select species for both screening and intensive site-specific studies.

It is also important that the target species be easy to identify taxonomically. There are significant species-specific differences in bioaccumulation potential, and many closely related species can be similar in appearance. Reliable taxonomic identification is essential to prevent mixing of closely related species with the target species. It is also practical and cost-effective to sample target species that are abundant, easy to capture, and large enough to provide adequate tissue samples for chemical analyses.

Note: Under no circumstance should individuals of more than one species be mixed to create a composite sample. Final selection of target species will require the expertise of state fisheries and/or biologists with knowledge of local species that best meet the selection criteria and knowledge of local human consumption patterns. Although, ideally, all fish species consumed

from a given waterbody by the local population should be monitored, resource constraints may dictate that only a few of the most frequently consumed species be sampled.

Note: Recent studies (not published) have shown PFAS concentrations do not follow the same patterns of bioaccumulation as other contaminants found in fish, such as PCBs and mercury. The size of the fish, lipid content, and predatory status are not always strong predictors of PFAS concentration, and a wider range of species may need to be considered to adequately determine the extent of contamination in fish.

Selection of the most appropriate sampling period is very important. Sampling should be conducted during the period when the target species is most frequently harvested, unless it does not coincide with the legal harvest season of the target species or the target species spawns during this period.

Note: If the target species can be legally harvested during its spawning period, then sampling to determine contaminant concentrations may be conducted during this time. See EPA's *Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories. Volume 1: Fish Sampling and Analysis* [EPA, 2000a] for a more detailed description of selection of species and sampling times.

D. Catch, label and process fish for shipping to the lab

Although the portion typically eaten may vary by species and/or the dietary habits of the fisher population of concern, most fishers in the United States consume fish fillets. EPA recommends that contaminant concentrations be measured using skin-on fillets for scaled fish species and skinless fillets for scaleless fish species (e.g., catfish)" [EPA, 2000a]. If the population of concern has dietary habits that suggest consumption of fish portions other than the fillet, health assessors may want to consider processing fish portions that would offer a more accurate estimation of exposure.

Due to the above assumptions, the EPA recommends that fish fillets be used in fish sampling and analysis. Fillets should not include any internal organs, and all bones should be removed. The fillets are generally ground and homogenized before analysis to ensure even distribution of contaminants throughout the samples [EPA 2000a]. Some state sampling programs (e.g., Connecticut) do not remove the skin for scaleless fish, like catfish and eel, because some members of the population do not remove the skin before consumption. Site specific information on fish preparation should be considered when available.

After samples are collected, they may be frozen whole until processed at a laboratory (up to 1 year of holding time before analysis), or, in some cases, filleted in the field and then shipped on ice to the lab. See Tables 6-4, 6-5, and 6-8 in EPA's *Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories. Volume 1 for fish and shellfish sampling and shipping strategies* [EPA 2000a].

Thorough documentation of all field sample collection and processing activities is necessary for proper interpretation of field survey results. Use of preprinted waterproof data forms, indelible

ink, and writing implements that can function when wet is advised. EPA recommends the following four separate preprinted sample tracking forms should be used for each sampling site to document field activities from the time the sample is collected through processing and preservation until the sample is delivered to the processing laboratory:

- Field record form
- Sample identification label
- Chain-of-custody (COC) label or tag
- COC form.

See templates in Figures 6-3 through 6-8 in EPA's *Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories. Volume 1* for fish and shellfish sampling and shipping strategies [EPA 2000a].

E. Laboratory resection, processing and analysis

Resection and Processing

Once shipped to the laboratory, whole frozen samples should be thawed and filleted. In accordance with EPA guidelines, samples may be homogenized as composites before analysis. Laboratory processing of fish fillet composite homogenate samples for analysis is outlined in Figure 7-1 of EPA's *Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories. Volume 1* [EPA, 2000a]. However, the choice to homogenize samples as composites depends on whether information about the contaminant's intra-species variation is needed.

Whole fish (if not immediately frozen for later analysis) are shipped or brought to the sample processing laboratory from the field on wet or blue ice within 24 hours of sample collection. If possible, fillets should be resected within 48 hours of sample collection. Ideally, fish should not be frozen prior to resection because freezing may cause internal organs to rupture and contaminate edible tissue. However, if resection cannot be performed within 48 hours, the whole fish should be frozen at the sampling site and shipped to the sample processing laboratory on dry ice. Fish samples that arrive frozen (i.e., on dry ice) at the sample processing laboratory should be placed in a $\leq$ -20° C freezer for storage until filleting can be performed. The fish should then be partially thawed prior to resection.

Note: If the fillet tissue is contaminated by materials released from the rupture of the internal organs during freezing, the fillet tissue may be eliminated as a sample or, alternatively, the fillet tissues can be rinsed in contaminant-free, distilled deionized water and blotted dry. Regardless of the procedure selected, a notation should be made in the sample processing record.

Analysis

Currently, no standard analytical methods exist (from EPA or any voluntary consensus standard bodies) for PFAS analysis in any matrices. Two publications provide documented methods for analysis of PFAS in fish tissue [Delinsky, Strynar, Nakayama, Varns, Ye, McCann and Lindstrom, 2010; Stahl, Snyder, Olsen, Kincaid, Wathen and McCarty, 2014]. In general, PFAS are extracted from homogenized composite samples via solid-phase extraction. The eluate is analyzed by tandem high-pressure liquid chromatography and mass spectrophotometry, and compared to standard curves from spiked amounts of PFAS.

PFAS analysis in fish tissue is specialized and not conducted by all laboratories. Laboratories selected for analysis must be accredited by the National Environmental Laboratory Accreditation Program (NELAP), or similar federal or state entity, for analysis of PFAS in fish tissue. Laboratories should be contacted prior to any fish collection and processing to ensure the methods used are adequate for the purposes of the study or project.

Fish Consumption Guidance Methodology

Most states and tribes develop risk-based fish consumption guidance following *EPA Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories Volume 2 Risk Assessment and Fish Consumption Limits* [EPA, 2000b]. The method uses species-specific data on concentrations of individual contaminants to determine how often it is safe to eat a particular species.

The maximum number of recommended meals of fish per month is calculated based on a health-based reference dose (RfD) and a measured concentration of contaminant using some form of the equation below:

$$meals/month = \frac{RfD(\mu g/kg/d) \times 70kgbw \times 30.44days/month}{Concentration\ in\ fish\ \left(\frac{\mu g}{g}\right) \times 227gfish/meal}$$

Body Weight and Meal Size

EPA's 2011 guidance recommends an average fish meal size of 227 grams (8 oz.) of fish for a 70 kg (150 lb) person [EPA, 2011]. The Great Lakes Protocols also assumes this meal size to body weight ratio. This meal size was derived from the Michigan Anglers Survey [West *et al.*, 1989], however, it could be adjusted by body weight for specific populations. The EPA guidance allows for using other ratios, and programs do vary in their assumptions for meal size and body weight when determining recommendations. Some examples of different assumptions used are shown below:

- 2017 EPA-FDA, *Advice about Eating Fish and Shellfish,* uses a meal size of 113 grams for body weight of 75 kg
- Multiple programs use a 60kg body weight for women
- Michigan uses a meal size of 227 grams for 80 kg body weight

Health-based Guidance Values Used for Screening

Health-based guidance values for some PFAS have been developed by federal, state, and international agencies using a variety of critical studies, endpoints, and methods. A summary of these guidance values are provided below. In general, these guidance values are estimates of a daily exposure dose that is not expected to lead to a non-cancer health risk over a set period of time. These guidance values are used to identify exposures that could potentially be hazardous to human health. However, exposure above a guidance value does not mean that health problems will occur.

PFAS guidance values are derived by first conducting a comprehensive literature review to identify a critical study and endpoint. The critical study must establish a dose-response relationship (i.e., a no observed adverse effect level (NOAEL) and/or lowest observed adverse effect level (LOAEL) or other data amenable to dose-response modeling). This dose-response information is then used to determine a human equivalent dose (HED) point of departure (POD) for calculation of the health based guidance value. The HED POD is often derived from a modeled serum concentration representing either an NOAEL or LOAEL experimental dose from the critical study. Finally, uncertainty factors are applied to the POD to account for toxicodynamic and toxicokinetic differences between species, variability within species, as well as sources of uncertainty associated with the experimental design of the critical study (ex: study duration, route of exposure, etc.).

As shown in Table 1, health-based guidance values have been developed by Minnesota Department of Health (MDH), Michigan Department of Community Health (MDCH), Health Canada (tolerable daily intake, TDI), and EPA (as part of a Drinking Water Health Advisory).

Table 1. Health-Based Guidance Values for PFOS and the Associated Fish Consumption Advice

Health Based Guidance Value Source	Study	Critical Endpoint	Point of Departure HED (mg/kg/day)	Uncertainty Factors	Health Based Guidance Value (µg/kg/day)	Maximum concentration 1 meal/week advice (ng/g)	Fish Advisory Program
MDH RfD 2008	Seacat et al. (2002)	Liver	0.0025	total uncertainty factor of 30 (3 for animal to human toxicodynamic differences and 10 for human to human variability)	0.08	200	AL, IL*, MN, OR*, WI
MDCH RfD 2014	Seacat et al. (2002)	Liver	0.00041	total uncertainty factor of 30 (3 for animal to human variability not accounted for in the human equivalency dose calculation and 10 for human to human variability)	0.014	38	MI
Health Canada TDI 2016	Butenhoff et al. (2012)	Liver	0.0015	total uncertainty factor of 25 (2.5 for animal to human variability not accounted for in the human equivalency dose calculation and 10 for human to human variability)	0.06	160	Ontario
EPA Health Advisory 2016b	Luebker et al. (2005a)	Developmental	0.00051	total uncertainty factor of 30 (3 for toxicodynamic differences between animals and humans and 10 for human to human variability)	0.02	50	CT**, WA**

MDH-Minnesota Department of Health; MDCH Michigan Department of Community Health
* Adopted methodology, no advice issued yet
** Draft for screening purposes, no advice issued yet. CT would use for sensitive population only

Glossary of Terms

1. **Human Equivalent Dose (HED):** The human dose of an agent that is believed to induce the same magnitude of toxic effect as the experimental animal species dose. This adjustment may incorporate toxicokinetic information on the particular agent, if available, or use a default procedure, such as assuming that daily oral doses experienced for a lifetime are proportional to body weight raised to the 0.75 power.
2. **Lowest-observed-adverse-effect level (LOAEL)**: The lowest tested dose of a substance that has been reported to cause harmful (adverse) health effects in people or animals.
3. **No-observed-adverse-effect level (NOAEL):** The highest tested dose of a substance that has been reported to have no harmful (adverse) health effects on people or animals.
4. **Point of Departure (POD):** The dose-response point that marks the beginning of a low-dose extrapolation. This point can be the lower bound on dose for an estimated incidence or a change in response level from a dose-response model, a NOAEL or LOAEL for an observed incidence, or change in level of response.
5. **Reference dose (RfD):** An EPA estimate, with uncertainty or safety factors built in, of the daily lifetime dose of a substance that is unlikely to cause harm in humans.
6. **Tolerable Daily Intake (TDI):** The daily dose of a chemical that is unlikely to lead to adverse effects in humans over a lifetime of exposure.
7. **Uncertainty factor (UF):** Mathematical adjustments for reasons of safety when knowledge is incomplete. For example, factors used in the calculation of doses that are not harmful (adverse) to people. These factors are applied to the lowest-observed-adverse-effect-level (LOAEL) or the no-observed-adverse-effect level (NOAEL) to derive a minimal risk level (MRL). Uncertainty factors are used to account for variations in people's sensitivity, for differences between animals and humans, and for differences between a LOAEL and a NOAEL. Scientists use uncertainty factors when they have some, but not all, of the information from animal or human studies to decide whether an exposure will cause harm to people (also sometimes called a safety factor).

List of Appendices

Appendices to this guidance include the following:
Appendix A: Summary of Existing Fish advisories for PFOS
Appendix B: Environmental Standards for PFAS used in Other Countries
Appendix C: Various PFAS Measured at Different Sites
Appendix D: Additional Recommended Literature on PFAS in Fish

Prepared by:

Aaron Young, PhD
Agency for Toxic Substances and Disease Registry

Rachel Worley, PhD
Agency for Toxic Substances and Disease Registry

Luis O. Rivera-González, PhD
Agency for Toxic Substances and Disease Registry

Sharee Rusnak, MSPH, ScD
Connecticut Department of Public Health

David Jones, MS
Minnesota Department of Health

Patricia McCann, MS
Minnesota Department of Health

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Appendix A. Summary of Existing Fish advisories for PFOS

Fish Consumption Advisory Program							
Fish Advisory Parameters	Alabama	Michigan	Minnesota*	Oregon*	Wisconsin	Ontario Canada**	New Jersey*\
RfD (µg/kg/d)	0.08	0.014	0.02	0.08	0.08	0.06	0.0018
RfD source	MDH 2008; ADPH	MDHHS	EPA 2016	MDH 2008; Oregon Health Authority 2013	MDH 2008; WDNR	Health Canada TDI	NJDEP 2018 MCL
BW (kg)/meal size (g)	70/227	80/227	70/227	70/227	70/227	70/227	
Fish Anatomy Analyzed	Fillet	Fillet	Fillet	Fillet	Fillet	Fillet	
Meal Advice categories concentration ranges (ng/g):							
General Population							
Unrestricted	≤40				≤40		≤0.56
16 meals/month OR 4 meals/week		≤9					
12 meals/month OR 3 meals/week		>9-13					
8 meals/month OR 2 meals/week		>13-19				<80	
4 meals/month OR 1 meal/week	>40-200	>19-38	>10-50	>200[b]	>40-200	>80-160	>0.56-3.9
2 meals/month		>38-75				>160-320[a]	
1 meal/month	>200-800	>75-150	>50-200		>200-800	>320-640	>3.9-17
4 meals /year							>17-51[a]

1-2 meals/year		6/yr: >150-300					>51-204
0 meal/month OR Do Not Eat(DNE)	>800	>300	>200		>800	>640	>204
Program contacts	**John A. Guarisco**	**Jennifer Gray**	**Pat McCann**	**Rebecca Hillwig**	**Sean Strom**	**Satyendra Bhavsar**	

Abbreviations: ADPH- Alabama Department of Public Health; MDH-Minnesota Department of Health; MDHHS- Michigan Department of Health and Human Services; WDNR- Wisconsin Department of Natural Resources; TDI- Tolerable Daily Intake; RfD- USEPA Reference Dose; DNE- Do Not Eat; SP- Sensitive Populations; PFOS- Perfluoralkyl sulfonate; PFAS- Poly- and perfluoroalkylated substances

* Preliminary draft methodology, no advice issued yet

**uses same RfD for all populations but does not provide advice between 1/week and DNE for SP. ∑PFAS is assessed against the benchmarks

[a]Level of DNE advice for sensitive populations

[c]New Jersey Department of Environmental Protection (NJDEP) also has fish consumption advice for PFOA and PFNA

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Appendix B: Additional Environmental and Health-Based Standards for PFAS used in Other Countries

Australia

Table B1 comes from Australia's Cooperative Research Centre for Contamination Assessment and Remediation of the Environment (CCRCARE). They have derived water screening levels for application to fish consumption separate from drinking water standards. Table B2 shows water Health Screening Levels (HSLs) from the Australian Government Department of Health's Food Standards Australia New Zealand. From the two documents the fresh water HSL for fish consumption is lower than that of Drinking water (this seems to be protective of bioaccumulation, which CCRCARE states has not proven to be an issue with PFOA)

Table B1. Summary of derived surface water and sediment HSLs for PFOS and PFOA (CCRCARE 2017)

Media	PFOS + PFHxS	PFOA
MPCfish	270 µg/kg	2700 µg/kg
HSLfresh water, fish consumption	21 ng/L	210 ng/L
HSLmarine water, fish consumption	616 ng/L	6,100 ng/L
HSLsediments	22 µg/kg	220 µg/kg

MPC – Maximum Permissible Concentration

Table B3. Australia's Department of Health sponsored Food Standard Australia New Zealand (AGDH 2017)

Toxicity reference value	PFOS/PFHxS	PFOA
Tolerable daily intake (ng /kg bw/day)	20	160
Drinking water quality value(ng/L)	70	560
Recreational water quality value (ng/L)	700	5,600

Europe

The European Food and Safety Authority has derived a Tolerable Daily Intake (TDI) of 150 ng/kg/day for PFOS. This was derived from a study on Cynomolgus monkeys that observed a NOAEL of 0.03 mg/kg/day. And Uncertainty factor of 200 was applied; 10 for intraspecies, 10 for interspecies, and 2 for duration of exposure [EFSA 2008].

Canada

Table B3 shows the federal environmental quality guidelines (FEQGs) for PFOS used in Canada (2017) that includes tissues from other animals than fish. Specific health-based values and fish consumption guidance for Ontario, Canada (not shown) are offered in the Table 1 of the guidance and in Appendix A respectively.

Table B3. Canadian federal environmental quality guidelines for PFOS

Water (ng/L)	Fish Tissue (ng/g wet weight)	Wildlife Diet (ng/g wet weight food)	Bird Egg (ng/g wet weight)

		Mammalian	Avian	
6000	8300	4.6	8.2	1900

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Appendix C: Various PFAS Detected at Different Sites

The following table reviews several studies included in Appendix D and the various types of PFAS detected in each study. Although PFOS is more likely to be detected, and PFOS and PFOA are the only PFAS with health based guidance values, the detection of additional PFAS may become more relevant with the growing knowledge surrounding the health effects of PFAS, their degradation in the environment, and differences in environmental concentrations based on the source of PFAS contamination.

PFAS	Great Lakes (Stahl 2014)	Urban Rivers (Stahl 2014)	2017 PHA Wursmith AF base[a]	Delinsky 2010 MN lakes [b]	Delinsky 2010 Mississippi River [b]	Sinclair 2006 fish in NY lakes [d]	Christensen 2016 Male anglers serum in WI[e]	Hansen 2016[f]	EPA RfD mg/kg/d
1. Perfluorooctane sulfonamide PFOSA	X	X	X			X			
2. Perfluorooctane sulfonate PFOS	X	X	X	X	X	X	X	X	0.00002
3. Perfluorononanoic acid (PFNA) (C9)	X	X	X				X	X	
4. Perfluorundecanoic acid (PFUnA) (C11)	X	X	X		X		X		
5. Perfluordecanoic acid (PFDA) (C10)	X	X	X	X	X		X		
6. Perfluordodecanoic acid (PFDoA) (C12)	X	X	X		X				
7. Perfluorooctonoic acid (PFOA) (C8)		X	X			X	X		0.00002
8. Perfluorohexane sulfonate (PFHxS)(C6)		X	X		X		X		
9. Perfluortridecanoic acid (PFTriA)		X	X						
10. Perfluoroheptanoic acid (PFHpA) (C7)		X					X		
11. Perfluoropentanoic acid (PFPeA) (C5)		X							
12. Perfluorohexanoic acid (PFHxA)(C6)		X						x	

13. Perfluorobutanoic acid (PFBA) (C4)		X							
14. Perfluorobutanoic sulfonate (PFBS) (C4)									0.02

[a] 90% of PFAS in fish (fillet) was PFOS from Fire training facilities (Aqueous film-forming foams AFFF)
[b] Contamination likely from 3M manufacturing and improper disposal of PFAS. Concentration measured in fish (fillet)
[d] Analyzed fish (livers) from inland lakes in NY state with no PFAS contamination
[e] Increase in PFAS in serum related to meals/year of locally caught fish
[f] Norway study, in an area contaminated with Aqueous film-forming foams (AFFF). A significant, positive increasing trend was seen for fish consumption and serum concentrations of PFOS, perfluorohexane sulfonic acid (PFHxS), and perfluorononanoic acid (PFNA).

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Appendix D: Additional Recommended Literature on PFAS in Fish

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